EFFECTIVENESS OF LIGHT-EMITTING DIODES IN REDUCTION OF SEA TURTLE BYCATCH IN ARTISANAL BOTTOM-SET GILLNET FISHERY IN SELECTED SITES, NORTH-COAST KENYA

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DECLARATION

This thesis is my original work and has not been presented at any other University or any other Award.

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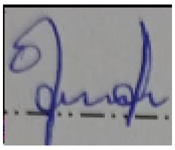
Signature:  Date: 31st July, 2023

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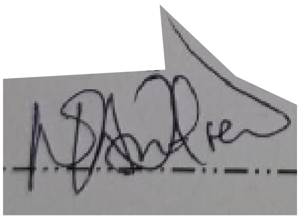
Signature:  Date: 31st July, 2023

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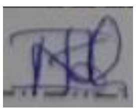
Signature:  Date: 31st July, 2023

DEDICATION

I dedicate this work to my lovely wife Susan and children; Cynthia, Gelas, Gabriel and Gadiel who stood by me as I pursued knowledge.

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ABSTRACT

The artisanal gillnet fishery is found in most of the world's oceans and is responsible for a high rate of sea turtle bycatch. Between December 2016 and December 2017, this study assessed the effectiveness of light-emitting diode (LED) lights in reducing sea turtle bycatch in bottom-set gillnet fishery at three fishing sites in north coast Kenya: Watamu, Ngomeni and Bwana Said. This study collected data through field experiments and 10 key informant interviews using semi-structured questionnaires. The data were analyzed using descriptive statistics in MS Excel and a t-test in the Statistical Package for Social Sciences (SPSS). During the investigation, ten boats each with a pair of control (non-LED) and illuminated (LED) gillnets were deployed, catching a total of 56 families representing 97 fish species. Both non-LED and LED gillnets had similar mean capture per unit effort (CPUE) of target species with common fish species such as whitespotted rabbitfish (*Siganus sutor)*, mackerel tuna (*Euthynnus affinis), and* honeycomb stingray (*Himantura uarnak)*. However, 56 sea turtles comprising 41 green, 9 hawksbills, 5 loggerheads, and 1 olive ridley were captured in control gillnets while 31 comprising 22 green turtles, 5 hawksbills, and 4 loggerheads were captured in illuminated gillnets representing an average by-catch of 8.7 turtles per boat during the study period. LED gillnets lowered the mean CPUE of sea turtles by 64.3% hence significantly reducing the sea turtle catch rate ($p < 0.05$). The green sea turtle (*Chelonia mydas*), was the main species captured (n=63) compared to other species. Increased net handling times (n=5), high equipment expenses (n=3) and a lack of awareness among fishermen about the technology's efficiency n=1) were ranked as topmost among the challenges associated with this assessment. To implement this technique of extensively minimizing sea turtle bycatch, the study recommends stakeholder support and further testing of this bycatch reduction strategy in the gillnet fisheries in key areas of Kenya's coast.

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ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
BRD	By-catch Reduction Device
CPUE	Catch Per Unit Effort
CRA	Commission on Revenue Allocation
FAO	Food and Agricultural Organization
GOK	Government of Kenya
IUCN	International Union for Conservation of Nature
IWC	International Whaling Commission
KMFRI	Kenya Marine and Fisheries Research Institution
LED	Light-emitting diode
SSF	Small Scale Fishery
TED	Turtle Excluder Device
UNEP	United Nation Environmental Programme
WWF	Worldwide Fund for Nature

CONTEXTUAL DEFINITION OF TERMS

Target species are provided as common catches, the species primarily sought by the fishermen in a certain fishery. The subject of directed fishing effort in a fishery.

Non-target species (**Bycatch, Incidental catch**) are species not specifically targeted as a component of the catch but which may be incidentally captured (Blackhart et al., 2006).

Bycatch is fish or other marine species that are caught accidentally while catching certain target species. Bycatch is either of a different species, the wrong size, or juvenile individuals of the target species.

Marine resources include a number of things: biological diversity, fish and seafood supplies, oil and gas, minerals, sand and gravel, renewable energy resources, tourism potential and unique ecosystems like coral reefs.

Sea Turtles/Marine turtles are reptiles of the order Testudines and of the suborder Cryptodira. The seven existing species of sea turtles are the green turtle, loggerhead sea turtle, Kemp's ridley turtle, olive ridley turtle, hawksbill sea turtle, flatback turtle, and leatherback turtle.

Artisanal nets (or **traditional/subsistence gillnet fishing**) are various small-scale, low-technology, low-capital, fishing practices undertaken by individual fishing households as opposed to commercial companies. These households make short (rarely overnight) fishing trips close to the shore on foot or using small boats. Their catch is usually not processed and is mainly for domestic and local market consumption.

Artisanal gillnet is a long rectangular netting anchored or otherwise fixed to the seabed or at times floating to catch fish when they come in contact with it. The net is kept in position by anchors or other weights, usually at both ends and marked on the surface with buoys and/or highflyers in a vertical position.

LED (**Light Emitting Diode**) is a semiconductor light source that emits light when current flows through it. Electrons in the semiconductor recombine with electron holes, releasing energy in the form of photons. This effect is called electroluminescence.

Effectiveness is the degree to which something is fruitful in producing the desired result; success. The capability of producing the desired result or the ability to produce the desired output. When something is deemed effective, it means it has an intended or expected outcome or produces a deep, vivid impression.

Catch per unit effort is the quantity of fish caught with one standard unit of fishing effort; e.g. number of fish taken per 1000 hooks per day or the weight of fish, in tons, taken per hour of trawling. CPUE is often considered an index of fish biomass (or abundance). Sometimes it is referred to as **catch rate**. (Wang et al., 2013)

Species is a group of living organisms consisting of similar individuals capable of exchanging genes or interbreeding.

Fishery refers to the sum of all fishing activities on a given resource, for example, a hake fishery or shrimp fishery. It may also refer to the activities of a single type or style of fishing on a particular resource, for example, a beach seine fishery or trawl fishery. The term is used in both senses in this document and, where necessary, its particular application is specified. The combination of fish and fishermen in a region, the latter fishing for similar or the same species with similar or the same gear types

Fishing effort is the total amount of fishing activity on the fishing grounds over a given period of time, often expressed for a specific gear type e.g. number of hours trawled per day, number of hooks set per day, or number of gillnets (length) each day. The fishing effort in this case would often be measured as the product of the total time spent fishing, and the amount of fishing gear of a definite type used in the fishing areas over a given unit of time. When two or more kinds of gear are used, they must be adjusted to some standard type to estimate the overall fishing effort.

CHAPTER ONE

1.0 INTRODUCTION AND BACKGROUND INFORMATION

The general background of the global and Kenyan coast fishery, its geographical state, territorial insurance, current fisheries control plans operationalized and people in various levels of improvement, various key stakeholders involved in the management of fisheries resources, and bycatch reduction strategies are presented in this chapter.

1.1 Marine fishery

The global need for fish as a food source poses a challenge for maintaining fish populations and protecting marine biodiversity. Fish consumption increased by 1.5 % each year from 9.0 kg per person in 1961 to 20.5 kg per person in 2017, with some countries reaching 50 kg per person (FAO, 2018). Therefore, fish consumption is predicted to rise at a rate of 1.6 percent each year (FAO, 2016). This huge production coupled with increase in consumption of fish increased the intake of animal protein by 20% and subsequently enhanced consumers' diets globally through several nutrient-rich foods (Bennett et al., 2018).

The decline in fish stock globally is mostly attributed to heavy commercial fishing (Nunoo et al., 2014; FAO, 2016; Lazar et al., 2018). The use of improved technology and methods, driven by increased demand for fish food and rigorous government intervention to develop fishing sector, has resulted in widespread decline of fish stock around the globe from overfishing. Over-fishing has proven to cause changes in composition and population of both targeted and non-targeted fish species and causes an unpredictable change in marine ecosystems (Maureaud et al., 2017), with its negative impacts spreading to all oceans and seas worldwide (Schoor, 2005). Bycatch can account for up to 40% of total biomass from capture fisheries (Davies et al., 2009; Kakai, 2019), and it is widely recognized as the single greatest threat to some of the world's most significant marine megafauna species (sharks, sea turtles, seabirds, and marine mammals). Huge marine vertebrates have historically had limited commercial value and are rarely designated target species in many nations, but they are occasionally caught as bycatch in many types of fisheries (Hall et al., 2000). Bycatch is now seen as the most serious threat to sea turtles, marine mammals, and seabirds, whose numbers have already been severely depleted (Lewison et al., 2014; Taylor et al., 2017; Anderson et al., 2020). With high rates of large vertebrate bycatch in artisanal gillnet fisheries (Lewison et al., 2014), it is thought to have population-level unique consequences on numerous megafauna species (Moore et al., 2013; Olendo et al., 2017; Wambiji et al., 2018; Temple et al., 2018).

Sea turtles are vital to the marine ecosystem as well as the terrestrial environment. Their functions range from ecological to humanitarian, and they are important for dietary, medicinal, cultural, economic, and religious purpose (Laqueux, 1998; Robinson and Redford, 1991; Freese, 1997, Okwema et al., 2004; Wamukota and Okwema, 2009). Turtles feed on jellyfish, crabs, sponges, tunicates, seagrasses, and algae, among other things. Predators such as crabs and sharks prey on juvenile turtles in the sea. Sea turtles are known to help reefs and seagrasses grow and develop (Bjorndal, 1980; Thayer et al., 1984; Maylan, 1988; McClanahan and Mangi, 2001; Leon and Bjorndal, 2002).

A portion of the sea turtle's life cycle must be completed on land, at the beach. They move nutrients from highly productive maritime ecosystems like seagrass beds to energy-poor areas like sandy beaches by coming ashore to breed (Frazier, 1975). This helps to reverse the normal flow of nutrients from land to sea, promoting vegetation development along the beach and minimizing erosion. The presence of sea turtles in a location may also provide employment and contribute to local development through tourist earnings.

Kenyan coastal waters are home to five different species of sea turtles (Okwema et al., 2004), which are, green turtles (*Chelonia mydas*), hawksbill turtles (*Eretmochelys imbricata*), olive ridley turtles (*Lepidochelys olivacea*), loggerhead turtles (*Caretta caretta*), and leatherback turtles (*Lepidochelys olivacea*). The green turtle, hawksbill, and olive ridley are three species known to nest on Kenyan sandy beaches (Frazier, 1975).

Even though the fact that loggerhead and leatherback turtles forage along Kenya's coast and migrate through Kenyan waters, they do so in a varied range of marine habitats, including coral reefs, seagrass meadows, and mangrove swamps (Wamukoya et al., 1997; Okwema et al., 2004). They however, do not nest along Kenya's coastline (Frazier, 1982; Church and Palin, 2003).

Kenyan sea turtle populations, like those across the world, are increasingly vulnerable to anthropogenic threats (IUCN, 2007; McLellan et al., 2012). Entanglement in fishing gear, poaching and illegal egg, meat, and shell trafficking, coastal development that destroy nesting habitat and disorients sea turtles, plastic or marine debris pollution and the effects of global warming are also common threats (Domingo et al., 2006; Rees et al., 2012; Jensen et al., 2016). Entanglement or accidental capture in commercial and artisanal fisheries is the major threat to sea turtles (IUCN, 1995; Spotila et al., 2000; Hays et al., 2003; Lewison et al., 2004; Jensen et al., 2016). Each year, the small-scale purse seine and artisanal gillnet fisheries in Kenya kill more than 250 sea turtles, including endangered green sea turtles (Wamukota, 2009; Watamu Turtle Watch, 2014). Despite the fact that capturing sea turtles is illegal in Kenya, the unintentional capture of sea turtles remains a significant threat to their population (WWF, 2009; Kimani et al., 2015; 2018).

Bycatch in fisheries has been identified as a major threat to sea turtles around the world (WWF, 2009). The interaction of small-scale coastal gillnet fisheries with sea turtles has been shown to be comparable to, if not superior to, that of industrial pelagic fisheries (FAO, 2009). Over 70% of sea turtle interactions with fisheries around the world result in unintentional capture (Molony, 2005; FAO, 2009), posing a substantial source of mortality for sea turtles (WWF, 2016). The Local Ocean Trust in Kenya on average recorded around 270 turtle deaths each year as a result of interactions with artisanal gillnet fisheries in the Watamu coastal fishing communities (Local Ocean Trust program manager, *Pers. Comm, September 20, 2015;* Kakai, 2019). This high rate of incidental capture and mortality in coastal fisheries constitutes a significant threat to sea turtle recovery and management, and has thus become the focus of contemporary sea turtle conservation efforts.

Several studies have found that using light-emitting diode (LED) lights to illuminate fishing nets can minimize sea turtle capture by up to 40% while having no effect on the catch of targeted fish (Wang et al., 2010, 2013; Ortiz et al., 2016; Kakai, 2019). These studies employed either LED light sticks or chemical light sticks to illuminate areas of nets and found that they reduced sea turtle bycatch rates while keeping catch rates of the target species within desired ranges (Wang et al., 2010, 2013).

Bycatch reduction technologies (BRTs) have been developed for a small number of fisheries to help lessen the negative effects of fishing (Cox et al., 2007). The usage of circle hooks in longline fisheries (Gilman et al., 2006; Serafy et al., 2012) and Turtle Excluder Devices (TEDs) in shrimp bottom trawl fisheries have received a lot of attention (Crowder et al., 1994, 1995; Watson et al., 2005; Lewison and Crowder, 2006; Read, 2007; Jenkins, 2011). The protection of nesting habitats and the ongoing raising of awareness of sea turtle conservation among local communities are critical to the long-term conservation of sea turtles in Kenya (Okemwa et al., 2004).

Fisheries-related methods to prevent sea turtle bycatch have been tried in Kenya, particularly in the bottom trawl shrimp fishery in the Malindi-Ungwana Bay area, where Turtle Excluder Devices have been used (Fennessy et al., 2008). However, the development of bycatch mitigation methods for gillnets, one of the most common artisanal fishing gear types, has been gradual (Melvin et al., 1999; Gilman et al., 2006; Wambiji et al., 2018; IWC, 2019).

Kenyan coast has an estimated artisanal fishery effort of over 3,500 boats operated by over 14,000 fishermen who fish 5-7 days per week (Government of Kenya, 2016; Kimani et al., 2018). Fish from the families Siganidae, Scaridae, and Lethrinidae, in general, dominate the captures, indicating the most plentiful and commercially important species. At least 13 species dominate and characterize more than 75% of the total catch of commercially important species landing (Hicks and McClanahan 2012; Tuda et al., 2016). Six of the most common species are the shoemaker spinefoot rabbitfish (*Siganus sutor*), which represents 11% of the artisanal fish landings, marbled parrotfish (*Leptoscarus vaigiensis*), pink ear emperor (*Lethrinus lentjan*), blackspot snapper (*Lutjanus fulviflamma*), thumbprint emperor (*Lethrinus harak*), and Carolines Parrotfish (*Calotomus carolinus*). The emperor, rabbitfish, rays, sharks, kingfish, tuna flounder, needlefish, lobster, and halfbeak are just a few of the benthic and demersal species targeted by bottom set gillnet (Samoilys et al., 2011). Therefore, since five species of sea turtles use the same waters as fishing vessels (Amiteye, 2002), quantifying sea turtle incidental capture in the artisanal bottom set gillnet fishery is critical and imperative, as is looking into the use of LED lights to reduce sea turtle captures as a bycatch reduction tool.

Protecting Kenya's sea turtles is clearly critical for the species' local and global recovery, as they play an important role in ocean ecosystems by maintaining healthy seagrass beds and coral reefs, providing important habitat for other marine life, assisting in the balance of marine food webs, and facilitating nutrient cycling from water to land.

1.2 Statement of the problem

Gillnets are well acknowledged globally as one of the fishing gears with the highest rate of sea turtles’ bycatch and death (Northridge, 1991; Echwikhi et al., 2010a; Sergio et al., 2017). Sea turtle mortality has been linked to bycatch in artisanal gillnet fisheries around the world (FAO, 2004; Bourjea et al., 2008; WWF, 2009). Several studies have found that the interaction between small-scale coastal gillnet fisheries and sea turtles is equal, if not greater, than the interaction between sea turtles and industrial-scale pelagic fisheries (Godley et al., 1998a, b;

Domingo et al., 2006; McLellan et al., 2012). According to estimates, 70% of sea turtle interactions with small-scale gillnet fishing activities in the world result in capture (Molony, 2005; FAO, 2009; Kakai, 2019), causing substantial death for sea turtles (Domingo et al., 2006; Watamu Turtle Watch, 2014; WWF, 2016; Olendo et al., 2017; Kakai, 2019). According to research, bycatch and mortality of the loggerhead sea turtle linked to gillnet fisheries off the coast of Baja California Sur, Mexico, may be comparable to that of industrial-scale pelagic longline fisheries (Casale et al., 2005; Peckham et al., 2007, 2008; Casale, 2011; Nada and Casale, 2011; Lucchetti et al., 2015).

In the Kenya coastal fishery, gillnets of various lengths and mesh sizes are utilized, with variations depending on the size and species targeted (McCLanahan and Mangi, 2004; Government of Kenya, 2008). Gillnets are commonly used in the artisanal fishery in this study area due to their versatility and effectiveness in catches and operation (Government of Kenya, 2008), but result in a large number of sea turtles as bycatch (Okwema et al., 2004; Kakai, 2019). In the example of Watamu, a small coastal town on Kenya's north coast, personal discussion with Mr. Athuman of Local Ocean Trust (September 20, 2015) revealed that approximately 270 sea turtle deaths were attributed to interaction with fishing gears within Watamu in the coastal fishery each year.

Several studies have indicated growing desires between fishermen wanting to sustain or conserve their livelihoods and sea turtle conservationists who seek to protect the endangered species. Therefore, there is need for interventions that will help protect the threatened species in their habitats while ensuring that the fishermen still make a living from fishing activities or their livelihoods as proposed in this study in the Kenyan context.

1.3 Goal and objectives of the study

The goal of this study was to assess the effectiveness of light-emitting diodes for the reduction of sea turtle bycatch in an artisanal bottom set gillnet fishery in selected sites, in north-coast Kenya. The specific objectives to achieve this goal were:

1. To quantify sea turtle capture rate in the artisanal bottom set gillnet fisheries at Watamu, Ngomeni and Bwana Said fishing sites

2. To compare captures of sea turtles in bottom set gillnet fisheries with unmodified and modified (gear illuminated with LED lights) fishing gear within the study sites
3. To evaluate catch quantity and composition of target fish species in unmodified and modified (gear illuminated with LED lights) fishing gear in the three sites

1.4 Hypothesis

i. There is no significant effect on sea turtles bycatch rate between the modified and the unmodified bottom set gillnets,
ii. There is no effect on the capture rate and composition of target fish between modified and unmodified bottom set gillnets.

1.5 Justification of the study

In recent years, modifying visual cues with lights has been linked to a potential bycatch reduction method for bottom set net fisheries. LED lights and light sticks mounted to gillnet float lines (Wang et al., 2010, 2013; Lucchetti et al., 2014; Ortiz et al., 2016; Virgili et al., 2018; Kakai, 2019) have been seen to reduce turtle bycatch while maintaining target species catch rates. By illuminating artisanal gillnets with green LED lights (Wang et al., 2010; Ortiz et al., 2016) or UV light, bycatch decreased from 63.9 % to 39.7 % in the Northern and Southern Pacific coast (Wang et al., 2013). In the Adriatic Sea, Virgili et al., (2018) found that employing

UV light in bottom set-gillnet fisheries in deep waters reduced bycatch by 100 % while maintaining commercial catch efficacy. Wang et al. (2010) and Ortiz et al. (2016) investigated gillnet lighting with green LED lights by linking control and experimental vessels, but this design does not reflect actual conditions in artisanal fishing, as vessels often fish independently of other vessels. Furthermore, while net illumination has been proven to reduce the capture rate of green marine turtles (*Chelonia mydas*) (Wang et al. 2010), it has yet to be tested in a natural setting on other marine turtles, including the globally threatened leatherback, hawksbill, and loggerhead (Ortiz et al. 2016). Because local environmental factors influence the efficiency of lights (Wang et al. 2013; Kakai, 2019), it is critical to evaluate net illumination in several sites with various sea turtle species.

As a result of the above-mentioned issues and taking into account past BRD trials, the current study sought to (i) compare the capture performances of a flexible (Flexgrid) LED in bottom set gillnets; and (ii) examine the efficacy of LEDs to reduce sea turtle bycatch in bottom set gillnet fisheries to add to or advance what has already been experimented by Virgili et al., (2018). This study was to add to the growing body of information on sea turtle bycatch reduction technology in artisanal bottom set gillnets, as well as to evaluate bycatch reduction technologies that work for Kenya's bottom set artisanal gillnet fisheries. This research examined the rate of sea turtle bycatch in the bottom set artisanal gillnet fishery, as well as the usage of LED lights as a tool for reducing it. In the aforementioned study sites, the study tested the efficiency of LED light as an alternative fishing method/technique for reducing sea turtle bycatch without reducing target species catch rates.

Through a greater understanding of how to decrease or remove threats to sea turtles, the findings of this study contribute to effective management and conservation goals for sea turtles in Kenya, WIO region and globally. This is the first study of its kind in Kenya, and if adopted, will contribute to experimental data, in other fishing communities in Kenya to develop and manage artisanal bottom set gillnet fishery measures so as to reduce sea turtle bycatch.

1.6 Scope of the study

This research was conducted between December 2016 and December 2017 at three sites namely: Watamu, on the Kilifi County coast, at Watamu, Ngomeni and Bwana Said fishing sites. These three locations are part of the most productive and fishing sites along the Kenyan coastline. The testing of LEDs as a sea turtle bycatch reduction device in the artisanal bottom set gillnets in the three landing sites was the main emphasis of this research. In an experiment, fishermen attached LEDs on their nets and carried them on their daily fishing outings. All the observers in the study were small-scale fishermen and boat captains who were well-versed in the bottom-set gillnet fishery in their respective study sites. It was assumed that LEDs would reduce sea turtles' bycatch but, would not have any effect on the target species in the illuminated nets.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

This chapter reviews available literature on coastal artisanal gillnets and sea turtle globally and in Kenya. Previous studies and their outcomes in evaluating LED lights as a bycatch reduction strategy are also included. The purpose of this review was to provide knowledge and a framework for assumptions made in finding answers to this study's questions, as well as to meet the study's objectives.

2.2 The coastal artisanal fishery

Artisanal coastal fisheries can provide up to 99 % of the protein source for coastal communities, as well as over 80 % of household revenue, and are thus critical for food security in developing countries (Barnes-Mauthe et al., 2013; Foale et al., 2013; McClanahan et al., 2013). Despite this, they are frequently undervalued by the development policies of their respective developing countries (Henson and Winnie, 2004; Hardman et al., 2013; Aloo et al., 2014). Furthermore, artisanal fishermen work primarily for pay but also for food, both of which are poorly estimated (Obura, 2001; Ochiewo, 2004; Cinner et al., 2009a). As a result, their contribution to national revenue and livelihoods is undervalued. As seen in Kenya (Kaunda-Arara et al., 2003; McClanahan and Mangi, 2004), artisanal coastal fisheries are multi-gear, multi-species, and landed at diverse landing sites, but are indicative of many tropical fisheries across the world (Munro and Williams, 1985; Wright and Richards, 1985; Dalzell, 1996). As a result, they are challenging to keep track of and manage (Samoilys et al., 2017). If monitoring is carried out, it is common for total landings to be recorded without regard for fishing effort, rendering the data weak (Luckhurst and Trott, 2009). Overfishing and the use of damaging fishing methods and gears are increasingly widespread in these fisheries, and are typically associated with poverty, overpopulation, and poor resource governance (Allison et al., 2009; Gutiérrez et al., 2011). Despite the Kenyan coast having an Exclusive Economic Zone (EEZ) that extends 200 nautical miles offshore (FAO, 2009), the coastal artisanal fishing occurs primarily along a narrow continental shelf of 2.5 to 3.0 nautical miles (McClanahan and Mangi, 2004; Samoilys et al., 2011). Fringing coral reefs, which are found within 12 nautical miles of the coast, dominate the region (Fondo, 2004). The Funzi-Shirazi Bay, the Diani-Chale area, Malindi-Ungwana Bay, and the Lamu Archipelago are some of the productive inshore grounds (Fondo, 2004; Maina, 2012; Munga et al., 2012). Fishing activities along the coast are sometimes limited by monsoon weather patterns, particularly during the months of May to August (South-east monsoon), when the ocean is rough (McManus, 1996; McCLanahan and Mangi, 2004; Morison, 2004). The best fishing season is from Oct to March (during the north-east monsoon), when the sea is calm (Mbaru et al., 2010, 2011). Despite the fact that Kenya's EEZ is 200 nautical miles (FAO, 2009), Kenya's freshwater fisheries still much outnumber marine fisheries, with marine fisheries accounting for only around 10% of total annual fisheries production (Gomes, 2012). The marine sub-sector has an annual potential of between 150,000 and 300,000 metric tons, although it barely accounts for about 0.5 % of the country's GDP annually (Government of Kenya, 2010). The usage of simple fishing technology in extensively fished nearshore areas has been linked to the apparent low catches and returns (Muthiga and McClanahan, 1987). Due to the inability of local fishermen to venture into offshore waters, deep-sea fishing areas, which are thought to be richer in pelagic stocks, have been underutilized (FAO, 2009).

As a result, Kenya marine artisanal fisheries have historically received far less attention in terms of research and management (Muthiga and McClanahan, 1987; Obura, 2001a; GoK, 2004; Fondo, 2004, Kimani et al., 2018). Nonetheless, the importance of this sub-sector cannot be overstated, since it directly employs over 80,000 directly in key activities in the fisheries value chain – and supports livelihoods of a further 2.3 million people (processors, traders, and other dealers) (Government of Kenya, 2010; 2016; FAO, 2015). In Kenya, WIOFish database has identified 33 fisheries. These are 11 artisanal fisheries, 9 artisanal and predominantly subsistence fisheries, and 3 artisanal and less commercial fisheries (Everett et al., 2011). Gillnets, hand lines, beach seines, basket traps, cast nets, scoop nets, monofilament nets, trammel nets, and trolling nets, spear guns, and other gears are used in small scale fisheries (Government of Kenya, 2016; Kimani et al., 2018; Onyango et al., 2021; Osuka et al., 2021). Reef and pelagic fish, as well as elasmobranchs, are among the many species targeted. Any form of gear can be utilized to target a wide range of species.

Kenyan small-scale fisheries gears operate in a variety of habitats, with each fishery type having the ability to function in many habitats. The majority of small-scale fisheries operate in inshore habitats, as one would anticipate from small-scale fishing (Everett et al., 2011). Gillnets, beach seines, and fish fence traps are more likely to catch marine mammals, sea turtles, and elasmobranchs in artisanal fisheries (Wambiji et al., 2018; Bourjea et al., 2008; Kiszka et al., 2008; Temple et al., 2018).

2.3 The coastal artisanal gillnet fishery

Gillnets are a typical fishing gear that may be used in both inshore and offshore environments (Samoilys et al., 2011; Government of Kenya, 2016). They are made up of single or multifilament nylon with varying mesh sizes and thicknesses. Inshore gillnets are typically 20-50 meters long, 1.5 meters tall, and have a diagonal mesh size of 1-4 inches (2.5-11cm). Offshore gillnets can be up to 90 meters long, 8 meters tall, and have a mesh size of 2 to 5 inches (5-12 cm). The weight of the multifilament (string weight) varies between 24 and 36 lb. (10.9-16.3kg) for offshore nets and 9 lb. (4kg) for inshore nets. A series of 1 kg lead weights are fastened at the bottom, and 10–15 floats are fastened on float line of the gillnets. A bottom set gill net team is made up of two to five fishermen who work with net pieces that are joined end to end. They spread the net in the evening from an indicator buoy where the nets are left overnight for fish to entangle. Fish are caught in the nets by their operculum when entrapped, and when they try to get free, they entrap themselves even more. After that, the net is brought into the boat with its catch mostly in the early morning hours the following day. Gillnets can also be used to fish passively at the surface or in the middle of the water. Gillnets are used to catch emperors, among other benthic and demersal species. In the offshore waters outside the reef or in deeper lagoons, drift nets are regularly set up from motorboats or canoes propelled by sail power. The net is either tied to the boat while they drift together, or it is positioned at the surface and allowed to float freely in the current (See plate 1; Figure. 2B)

Plate 1. Fishers on their way to setting gillnets at the fishing ground (Photo credit. Kakai, 2017)

2.4 Sea Turtles bycatch in artisanal fishery

The accidental catch of unwanted species is a huge hazard to the world's marine resources (Davies et al., 2009; Hall et al., 2000; Kelleher, 2005). Bycatch of marine megafauna has ecological consequences (Lewison et al., 2004), reducing megafauna populations directly (Heppell et al., 2000; Wambiji et al., 2018; Temple et al., 2018) and altering trophic dynamics of marine systems indirectly (Heppell et al., 2000; Wambiji et al., 2018; Temple et al., 2018; Estes et al., 2011; McCauley et al., 2015). Bycatch of megafaunas (marine mammals, seabirds, elasmobranchs, and marine turtles) is a global challenge in marine resource management, as many megafaunas crisscross ocean basins, necessitating international action, coordination, and, in some cases, policy instruments to address bycatch at these large scales.

Green (*Chelonia mydas*), loggerhead (*Caretta caretta*), and hawksbill turtles (*Eretmochelys imbricata*) are the most common and widely distributed sea turtles in the WIO, with others being olive ridley turtles (*Lepidochelys olivacea*), and leatherback turtles (*Lepidochelys olivacea*) (WWF, 2016; Wambiji et al., 2018). Gillnetting, prawn/shrimp bottom trawling, and longlining are three fisheries that catch marine turtles in substantial numbers (FAO, 2006; Bourjea et al., 2008; Kakai, 2019). Nonetheless, with the exception of open marine fisheries in the Seychelles, La Reunion (France), and South Africa, the prevalence and impact of fisheries on sea turtles in the region are little understood. Furthermore, baseline parameters on sea turtle abundance and reproduction are only known from a few locations along Madagascar's and East Africa's shores, but are well known for islands such as the Seychelles Archipelago, the Comoros Archipelago and the French scattered islands.

Bycatch of sea turtles (particularly the green turtle) in gillnets, prawn, and shrimp bottom trawl fisheries has resulted in high mortalities in the region. In Mozambique, these fisheries may kill between 1,932 and 5,436 turtles each year in the Sofala Bank (Gove et al., 200; Pilcher and Williams, 2018). Similar conditions may exist in other parts of the region (Kenya, Madagascar, and Tanzania), but site-specific and current data are still scarce (Bourjea et al., 2008; Thoya et al., 2019). Although no bycatch numbers have been published, gillnets pose a major threat to green and hawksbill turtles, particularly off Zanzibar (5,329 gillnets documented in 2008 in Zanzibar and Pemba; Sobo et al., 2008). When Turtle Excluder Devices (TEDs) were not in use in Kenya, incidental catch rates of turtles in shrimp bottom trawls were estimated to be 100–500 turtles per year (Wamukoya et al., 1996). In Madagascar, sea turtle mortality in shrimp bottom trawlers was previously high however, mortality decreased after the introduction of Turtle Excluder Devices (TEDs) (Rakotonirina et al., 2006). According to a study done by Humber et al., (2011) the annual catch of sea turtles in the southwestern province of Tulear alone was between 10,000 and 15,000 per year. Purse-seining and longlining in pelagic waters have been reported to catch sea turtles by accident in the WIO region. Bycatch rates, on the other hand, are rather modest. Between 2009 and 2010, four loggerhead turtles were captured alive (0.28 turtles per 1,000 hooks) and released off the coast of Mayotte in 29 longline sets of 500 hooks (Kiszka et al., 2010). Sea turtle bycatch was estimated in the purse seine fishery based on data acquired from French and Spanish observer programs, which represented 17 of 1,958 observed fishing sets monitored between 2005 and 2008. Turtles were recorded occasionally and nearly entirely on tuna school sets associated with logs (95 %). During the observation period, a total of 74 individuals were caught (Amande et al., 2008). Quantitative data on bycatch levels for all fisheries in the WIO region is still lacking (Wambiji et al., 2018). Bycatch rates should be complemented by data on the abundance, reproductive characteristics, and spatial dynamics of sea turtle populations.

In other countries in the region, such as Madagascar, the lack of information is particularly noticeable for coastal artisanal fisheries, which also target sea turtles (Bourjea et al., 2008). Because of the culture of eating turtle, the Bajuni community for example in Kenya is seafaring and has well developed ways for turtle catching (Frazier, 1980). As a result, turtles, especially green turtles have long been an essential food source for these coastal people (Kakai, 2019), but their populations have declined owing to overexploitation, necessitating conservation. Those found guilty of poaching endangered species face steep penalties and tough prison sentences under the Wildlife Conservation and Management Act of 2019. However, the legislation's deterrent effect on poaching and bycatch is yet to be seen since there is significant evidence to attest to poaching. Sea turtle poaching and bycatch have an impact on population dynamics because it prevents new turtles from being recruited into the ecosystem.

During, 1990 to 2008, little over 85,000 sea turtles were caught as bycatch in gillnets, longlines, and trawls around the world, according to a study by Wallace et al., (2010). The same attitudes indicate that longlines were more likely to have a higher impact on turtle populations than gillnets, which also identified trends in the quantity of bycatch and potential population. Sea turtle populations have declined across the entire range in the WIO region and around the world

(Mancini et al., 2011). Turtles are caught for their meat and bycatch increases as fishing efforts intensify. High returns compared to fishing, a lack of adequate law enforcement, and the ease of escape in the sea are among the reasons that support poaching. Fishermen's decisions to capture sea turtles are heavily influenced by demand from traders and/or loyal clients, as well as the frequency of turtles in their fishing grounds (Mancini et al., 2011).

The main risks on the beach globally and in Kenya are egg predation, nesting inundation, bycatch, and poaching, which affect turtles at all phases of their lives (Bourjea et al., 2008; Olendo et al., 2017; Kakai, 2019). In Kenya, fishing bycatch has a significant mortality rate of sea turtles and other marine megafauna (Wambiji et al., 2018; Kakai, 2019), according to data collected by the Kenya Sea Turtle Conservation Committee (KESCOM) which was established in 1993 out of a necessity to address the plight of marine turtles in Kenya, between 1998 and 2008, 85 % of turtles seized on the Kenyan coast by artisanal and commercial fishing were killed for local consumption or trafficked. According to the Kenya national monitoring program, sea turtles and their nests were illegally caught in fishing gear or poached at a rate ranging from 10% (in areas with effective monitoring programs) to over 50% (in areas with no or poor monitoring programs) (FAO, 2009).

2.5 Sea turtles bycatch in artisanal gillnet fishery

Many sea turtles are threatened by the unintended capture in small-scale fishing (Hall et al., 2000; Peckham et al., 2007; Soykan et al., 2008; Gilman et al., 2010; Mangel et al., 2010; Anderson et al., 2011; Kakai, 2019). Previous research has linked high dramatic reduction in the population of a variety of sea turtle species (Lewison et al., 2004; Camhi et al., 2009), but, there is mounting evidence that the small-scale gillnet fishery, for a variety of reasons, poses a significant threat. Small-scale gillnet fisheries, which are less mechanized and have a low tonnage capacity (Chuenpagdee et al., 2006; Jacquet & Pauly, 2008; Goverment of Kenya, 2016), have large fleet sizes, a high relative density of fishing capacity, and occur in highly productive coastal oceans where many threatened species co-occur, combined with inadequate control and enforcement measures, putting huge pressure on sea turtles as bycatch precursor (Peckham et al., 2007; Soykan et al., 2008; Alfaro-Shigueto et al., 2010, 2011; Moore et al., 2010; Stewart et al., 2010). Entanglement in gill net operations is a common cause of sea turtle deaths in the fishing industry (Domingo et al., 2006; FAO, 2004; Bourjea et al., 2008; Olendo et al., 2017; Kakai, 2019).

Sea turtles are highly vulnerable to fishing nets, particularly gillnets and driftnets, in the marine environment, because with the exception of the leatherback, they are known to spend most of their lives in shallow coastal waters (Frazier, 1975; Eckert et al., 1999; Okwema et al., 2004). This easily exposes them to the excesses in activities by humans who still present the largest oceanic threat to sea turtles (Barkan, 2010).

Gillnet by-catch of sea turtles remains a major threat and has been a great source of concern for many fisheries managers because it presents a serious threat (Komoroske & Lewison, 2015). Sea turtle species have been recorded as subject to by-catch, especially from gillnet (Wallace et al., 2010). By-catch has resulted in the decline in several sea turtle species exerting surging and widespread ecological impacts (Wamukoya et al., 1997; Lewison et al., 2014). For populations of some already depleted species such as leatherback sea turtle (Dermochelys coriacea), by-catch remains the largest threat to their risk of extinction (D’Agrosa et al., 2000; Marsh et al., 2002; Read, 2008; Wamukota and Okwema, 2009; Rivalan et al., 2010; Wallace et al., 2013).

Gillnet fisheries by-catch has threatened the continued survival of several sea turtle species, which have experienced population declines over the past several decades. Over 70% of sea turtle interaction with gillnet results in turtle by-catch, and this presents a major source of sea turtle mortality around the globe (Soykan et al, 2008; Kimani et al., 2018). Wang et al (2013) also reported high turtle mortalities from gillnet fishery by-catch which makes it difficult to achieve any recovery of the sea turtle population by just increasing the hatchling production alone.

Incidental capture in gill nets is also responsible for a larger number of sea turtle kills around the globe (Peckham et al., 2007a, 2007b; Soykan, 2008; Wang, Barkan, Fisler, Godinez-Reyes,

& Swimmer, 2013; Kakai, 2019). Although turtles can remain underwater for long periods, they need to breathe atmospheric oxygen. A trapped turtle will struggle, significantly reducing its oxygen supply and shortening the time it has before it needs to reach air. The long struggles of these trapped turtles cause death through seawater infiltration into the lungs of the turtles.

Although sea turtle by-catch keeps increasing over the years, the true amount of global bycatch is not well documented as a result of a lack of observers and inaccurate catch reports (Barkan, 2010; IUCN, 2014). Bycatch is often discarded back to the sea, dead and unused, or secretly taken away for consumption because the sea turtles' species are either protected by regulatory policies or commercially valueless, and most of these discards are not reported due to the absence of observers. By-catch is however accidental since it is a problem for fishermen because it damages their fishing gear, takes time to remove from gear, and can result in the reduction of target catch (Barkan, 2010; Olendo et al., 2017).

Although several efforts have been made in the past to protect sea turtles, incidental capture in gillnet fisheries still threatens the survival of the sea turtle species (Frazier, 1982; Kimani et al., 2018). Mortalities result from the turtles either drowning after becoming entangled or suffering fatal injuries on-board the vessel. Because net entanglement can reduce swimming abilities, sea turtles caught in gillnets face a higher chance of mortality from drowning than those captured on a long-line hook (Bourjea et al., 2008).

The documented mortality from incidental gillnet entanglement in fishing is 18% (KESKOM unpublished data). Information seems also to indicate that the relative mortality due to gillnet fisheries either as targeted or incidental is approximately 95% of all documented turtle mortalities in Kenya (Wamukoya et al., 1997), with approximately 58% of sea turtles killed as a result of entrapment in fishing nets (Okemwa et al., 2004). Other documented sources of mortality are relatively low, with the main constraint being the lack of data on the foraging and developmental habitats of the turtles in Kenya and on turtles migrating out of Kenyan waters.

2.6 Sea turtles bycatch reduction technologies (BRTS)

There are various methods that have been developed to reduce by-catch considering by-catch poses a threat to the marine species populations. These methods, which aim to reduce fishing pressure and consequently, by-catch, include catch restrictions, area closures, devices, and fisheries timings. Other legislative attempts to reduce bycatch include a minimum mesh size limit (50mm), a 0.5-nautical-mile inshore trawling distance limit, and the prohibition of the sale of certain bycatch species (Fennessy et al., 2008).

Coastal gillnets catch sea turtles all around the world (Wallace et al., 2010), for example, was once legal but is now prohibited along the eastern seaboard of the United States (Gearhart, 2003), along the Pacific coast of Mexico (Peckham et al., 2007), in the Mediterranean (Echwikhi et al., 2010; Casale, 2011; Snape et al., 2013), and in the Caribbean (Lum, 2006; Echwikhi et al., 2010; Casale, 2011; Snape et al., 2013). The expedition of fisheries closures, especially in artisanal fisheries, however, is likely to encounter political obstructions in some countries (Barkan, 2010), as fishermen perceive the process as an attempt to reduce their catch and hence their income like it was the case in Kenya (Okwema et al., 2004; Wamukota, 2009; Watamu Turtle Watch, 2014). To reduce sea turtle bycatch in prawn bottom trawl fisheries in Madagascar, a number of mitigating measures have been applied, including mesh size restrictions, trawl gear size limits, closed seasons and areas, partial prohibition of nocturnal trawling, a limited number of permits, and effort zonation (Fennessy et. al., 2008).

Bycatch mitigation in artisanal fisheries, particularly gillnet fisheries, where the most vulnerable megafauna bycatch occurs, has received very little attention as compared to the use of Turtle Excluder Devices (TEDs) in shrimp bottom trawl fisheries (Gilman et al., 2006; Serafy et al., 2012; Crowder et al., 1994, 1995; Watson et al., 2005; Lewison et al., 2014; Read, 2007; Jenkins, 2011). In contrast, in other coastal fisheries, such as the WIO region's prawn bottom trawl fisheries, numerous successful attempts have been launched to limit bycatch, particularly of sea turtles and elasmobranchs (Fennessy et al., 2008). A turtle excluder device (TED) is made up of a metal grid of bars built into the net that open to allow sea turtles out of the net through a trap door while allowing shrimp to pass through the bars into the back of the net. Federal regulations of most countries require trawlers to install turtle excluder devices (TEDs) on the fishing gears. In Kenya, the use of Turtle Excluder Devices (TEDs) was made mandatory in 2003 after KESCOM had successfully campaigned for its usage in all trawlers operating within Kenyan waters. In 2008 the Tanzanian government sent a draft discussion paper to key stakeholders with the goal of drafting a prawn fishery management plan with an aim of reducing bycatch which was never successful. In Mozambique, the legislation mandated the use of TEDs since 2005. There are currently numerous initiatives to research prawn bottom trawl gear technology, for example the deployment of Nordmore grids produced positive results in South Africa, with a 60 % reduction in elasmobranch bycatch (Fennessy et al., 2008). The requirement to use TEDs was passed in 2003 and implemented in 2005 (Humber et al., 2011), however, TEDs were efficient at decreasing stranding rate of loggerhead and Kemp's ridley in the first three years after which the stranding rate increased possibly due to improper use of TEDs, inadequate size of TED openings, and poor TED use compliance, as reported by Lewison and others (2013). The huge size and heaviness of TEDs could be the possible cause of the device not being utilized in countries like Ghana (Barkan, 2013). TEDs have been reported to interfere with the setting and hauling of fishinggears and are also heavy to convey on fishing expeditions. The use of acoustic pingers to reduce dolphin bycatch in drift and bottom-set gillnets off Zanzibar is the only important mitigation approach in the region for artisanal fisheries to reduce sea turtles' bycatch in drift and bottom-set gillnets (Amir, 2010). The pingers are installed on gill nets along the float line from where they continuously emit noises at specified frequencies that deter marine mammals from approaching the gear. Fitting active pingers on gill nets that emitted a 300 ms pulse every four seconds has the tendency to reduce marinemammal bycatch by 90% (Campbell and Cornwell, 2008), for example in California, the use of pingers was successful at reducing marine mammal capture by a third of what nets without pingers captured. Despite pingers being successful at reducing marine mammals and sea turtles in fishery, pingers have been unpopular with fishermen due to the issues of coast, weight ang regulations associated with them (Campbell and Cornwell, 2008).

The focus on the use of circle hooks in longline fisheries (Gilman et al., 2006; Serafy et al., 2012), on the contrary, as a bycatch mitigation technique for gillnets, one of the most frequent gear types, have progressed slowly (Melvin et al., 1999; Gilman et al., 2006). Long-lines are more selective than nets but still result in significant bycatch of species like seabirds and sea turtles that prey on the bait attached to the hooks, hence the need for circle hooks (Barkan, 2010). Circle hooks have been used as alternatives to the traditional J-shaped hooks in long-line fisheries as another gear modification technique aimed at reducing sea turtle mortality. Effective use of circle hooks can reduce loggerhead sea turtle bycatch in long-line by 90% (Barkan, 2010). The circle hooks reduce sea turtle mortality by hooking the turtle in the mouth rather than deeper in the throat or stomach. This allows fishermen to unhook the turtles without causing serious injury or mortality. Circle hooks are also gear specific and work only in long-line fishery.

In California, buoyless nets use for reducing sea turtle by-catch in artisanal fishery has been investigated using bottom set gillnet nets (Peckham et al., 2008, 2012). The experiment was set up on the premise that reduced vertical profile of gillnets would result in reduced sea turtle by-catch. The buoyancy of the fishing was therefore reduced by increasing the distance between the buoys from 1.7 m interval on control nets to 8.7 m interval on experimental nets (buoyless nets), hence a 68% reduction in mean loggerhead turtle bycatch. However, the buoyless nets reduced the catch quantity which presented an important source of concern by local fishermen accepting to use the nets.

Shark shapes have been used or been adopted as sensory cues manipulation method to reduce sea turtle capture in fishing gears (Wang et al., 2010). Black shark shapes which are suspended in front of the gillnets along the float line serve as visual deterrent to reduce sea turtle bycatch. Effective use of shark shapes has demonstrated a significant reduction of green sea turtle bycatch in gillnets by 54% (Wang et al.,2013). Shark shapes used in artisanal demersal gillnet fishery also resulted in significant reduction in catch per unit effort (CPUE) of non-target species by 45% and mean catch value by 47.4% (Barkan, 2010). Notwithstanding, shark shapes have received relatively minimal usage due to the huge size of the shark shapes which present a great interference to the fishing process in terms of setting and hauling of nets.

Even though fish and sea turtles inhabit the same marine habitat, their differing lifestyles have led to enough variance in their sensory systems. Turtles have been found to be more sensitive to ultraviolet radiation than fish in studies comparing the visual ecology of fish and sea turtles (Wang et al., 2013). Sea turtles and pelagic fishes for example, are highly visual predators, and visual cues play an important role in attracting both groups of animals to fishing gear (Southwood et al., 2008). Sea turtles also have lenses and other optical media which transmit light to 320 nm, and have the capacity to detect light in the UV range (Mäthger et al., 2007). These variations have been included into gear modification technologies to enable fishing gears to catch specific species while lowering the rate at which endangered sea turtles are caught in nets. The development of mitigation measures for fisheries that interact with sea turtles therefore, is required to effectively reduce incidental capture rates of sea turtles and other species of bycatch. Southwood et al., 2008, Gilman et al., 2010 and Kakai, 2019 stipulated mitigation measures such as net illumination in a number of gear designs and an assessment of their effectiveness in a variety of gear types. However, costs and implications for fishermen, the target species capture, and the influence on other bycatch species must all be considered when implementing net illumination or other mitigating strategies (Cox et al., 2007). Bycatch reduction, particularly in bottom-set artisanal gillnets, has the potential to aid sea turtle population management and recovery. However, in coastal gillnet fisheries, there are minimal bycatch mitigation methods in place to decrease sea turtle interactions (Cox et al., 2007; Wamukota, 2009; Gilman et al., 2010; Wang et al., 2010, 2013; Watamu Turtle Watch, 2014, 2016). Consideration of the ecology, behavior and physiology of bycatch species is one solid technique for devising an effective mitigation intervention (Southwood & Avens 2010; Jordan et al., 2013). Sea turtles have been demonstrated to rely heavily on visual cues, especially when foraging (Constantino & Salmon, 2003; Wang et al., 2007; Young et al., 2012). According to bycatch mitigation research that takes advantage of this reliance on visual cues, net illumination could be an effective visual alert in reducing sea turtle interactions with gillnets (Swimmer et al., 2005; Southwood et al., 2008; Wang et al., 2010, 2013; Kakai, 2019). Bycatch reduction methods have been developed not only to reduce bycatch, but also to help fishermen maintain target catch returns (Wang et al., 2010; 2013). In Mexico and Peru, the use of light-emitting diode lights on driftnets demonstrated to be efficient at reducing bycatch rates of sea turtles while having no effect on target fish species (Barkan, 2010; Wang et al., 2010; Ortiz et al., 2016), when the control and experimental vessels were paired to evaluate net illumination with green LEDs (Wang et al. 2010; Ortiz et al. 2016). However, that kind of experiment is yet to be tested in a natural context on other chelonid turtles or the internationally threatened leatherback, hawksbill, and loggerhead (Ortiz et al., 2016). Since the efficacy of lights is influenced by local ecological dynamics (Wang et al., 2013; Alfaro-Shigueto et al., 2018; Ortiz-Alvarez et al., 2020), in order to avoid sea turtles extinction, it is critical to test net illumination with different sea turtles in different places (Lad OPO Network, 2020; Kakai, 2019).

The major goal of the current study was to evaluate the effectiveness of net lighting using hooked green-colored LED lights in reducing sea turtle bycatch in the Kenyan context of small-scale bottom-set gillnet fishing. This information could be useful in implementing Kenya's national strategy to reduce sea turtle bycatch and supporting regional efforts to protect endangered sea turtle populations.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Introduction

This chapter covers the study's locations, research design, study population, sample size and sampling techniques, data collection instruments, data gathering procedures, data analysis, and ethical considerations.

3.2 The study area

Between 1^{o} 41′ and 4^{o} 40′south, the Kenya coast stretches for around 640 kilometers in a north-northeast to south-southeast direction (UNEP, 1998; Okwema, et al., 2004). Except in the northern regions, where it extends to around 60 km offshore, the coast is characterized by a thin continental shelf (Newell, 1959). The East African Coastal Current (EACC) is a monsoon-driven coastal current that flows from the south, across the equator, and up the Somali coast into the Arabian Sea during the northern summer months of June to September, under the influence of the southeast monsoon (SEM) (Newell, 1959; Johnson et al., 1982). The EACC is destabilized and directed eastwards during the northern monsoon, where it meets the south-flowing Somali current off Kipini and Lamu areas (Schott and McCreary, 2001).

Fish migration and distribution, as well as fishing patterns and their impact along the Kenya coast, are influenced by the passage of ocean currents, seasonal changes in wind and ocean patterns, and their subsequent confluence (Brakel, 1984; Jury et al., 2010). Variation in oceanographic characteristics like salinity, sea surface temperature (SST), and chlorophyll have also been demonstrated to alter the distribution of fisheries resources in other researches (Newell, 1959; Johnson et al., 1982; Jury et al., 2010). Patchy reefs can be found around Kiunga and Malindi in the north, and Shimoni in the south. Fringing reef systems are well developed and present along the coastline except where Tana and Athi/Sabaki rivers discharge freshwater into the Indian Ocean, while patchy reefs can be found around Kiunga and Malindi in the north and Shimoni in the south (UNEP, 1998). Seagrass beds can be found in shallow lagoons, creeks, and bays, and are often linked to reef systems. Mangrove ecosystems are abundant on coastal Kenya (UNEP, 1998), where near-shore subtidal ecosystems are critical for recreational activities, tourist attraction, coastline stability, and natural disaster mitigation. Along the near-shore line, edible invertebrates and fish can be found.

The research was carried out in the Watamu, Ngomeni, and Bwana Said fishing sites, which are found in the north coast of Kenya's Indian Ocean in Kilifi County (Figure 1). Kilifi County, home to the three study sites, has over 1,110 gillnets, second highest in the country after Lamu County when compared to other coastal counties (Government of Kenya, 2014; Kimani et al., 2018). Maritime commerce and tourism are the main economic activities in urban areas like Kilifi, Watamu and Malindi, all which dependent on the rich biological diversity and environmental health. Food production, artisanal activities, and small retail and service businesses are the main economic activity outside of urban regions based on the study observations and Commission on Revenue Allocation (2012) and Kenya National Bureau of Statistics (2019). Prior knowledge of the presence of gillnet fishing, previous study occurrence of sea turtle species (Okwema et al., 2004; Kakai, 2019), and personal observation and interaction with the fishermen overtime were used to identify the sites. The sites were chosen based on the gillnet fishery's dominance and the abundance of sea turtles (Watamu Turtle Watch, 2014; Government of Kenya, 2016).

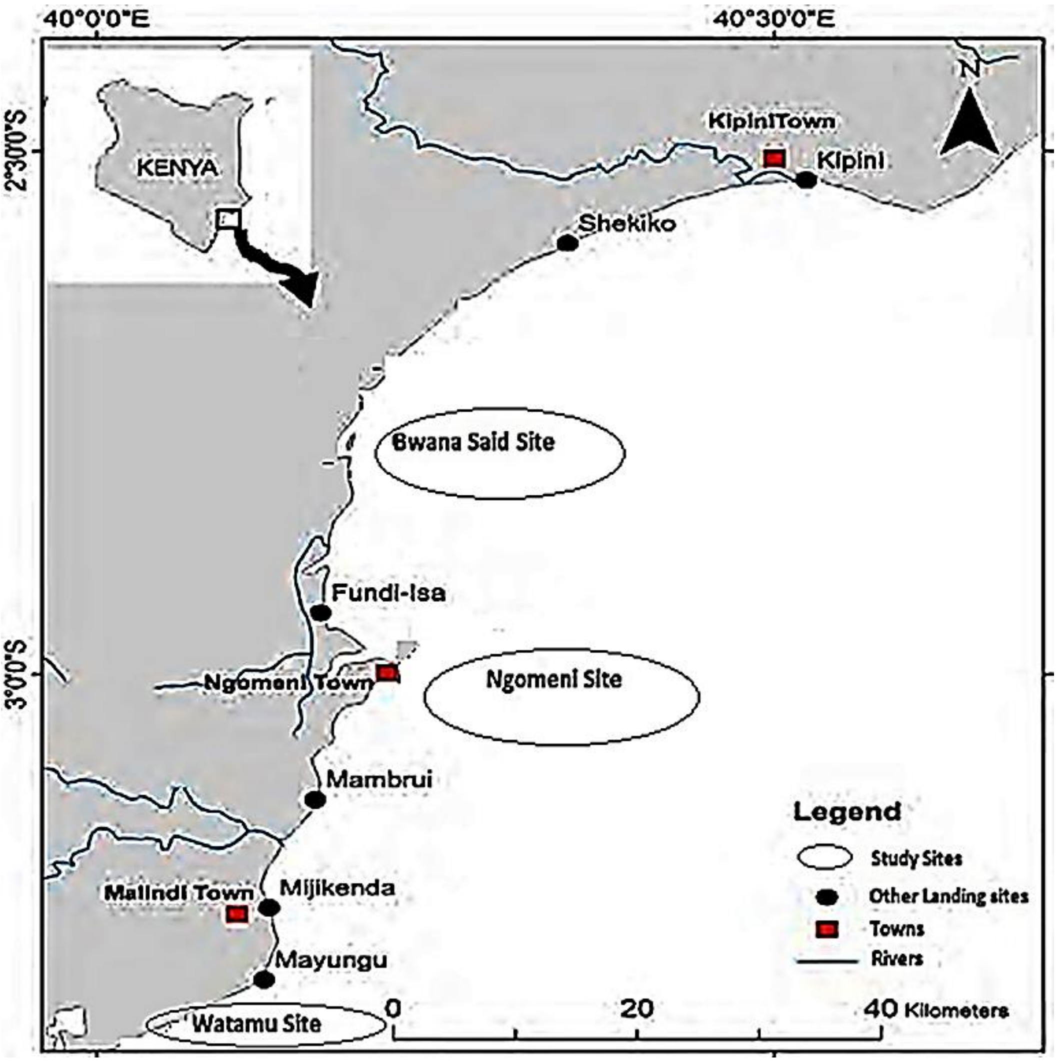

Figure 1. Map of Kenya (inset) showing the study area and fishing sites; Watamu, Ngomeni, and Bwana Said in north coast Kenya.

3.3.1 Watamu fishing site

The largest of the three fishing sites, Watamu is located in the coastal Kilifi County, some 25 kilometers south of Malindi town. It is rich in marine resources such as mangroves, fish, sea turtles, and coral reefs (Watamu Turtle Watch, 2014), however it is currently facing a number of anthropogenic and natural threats to its marine resources and livelihoods. The residents in the neighborhood are of diverse ethnicity including the Bajuni and the Giriama people (Frazier, 1980; Cinner et al., 2009). The area's community livelihoods are primarily reliant on natural resources, including fishing, peasant farming, tour guiding, and small trading with some of the villagers employed as casual laborers around the village (WTW, 2014).

3.3.2 Ngomeni fishing site

About 30 kilometers north of Malindi town is the Ngomeni fishing site. It has a population of about 4567 people and a household size of about 5-7 people on average (KNBS, 2019; CRA, 2020). The fishing site, like Watamu, is rich in marine resources including mangroves, fish, and sea turtles. The Bajuni make up the majority of the population, which is followed by the Giriama and Wata tribes. Fishing is the main source of revenue in the area, but trading and tourism-related businesses also contribute significantly to the community's livelihoods.

3.3.3 Bwana Said fishing Site

Bwana Said is about 75 kilometers from Malindi town and the smallest in terms of population but, it is the most destructive to sea turtle's population because of the Bajuni community migrant fishers from Tanzania (Cinner et al., 2009) and has the highest gillnets (Bwana Said landing site chair, Mr. Jilani, *Pers. Comm, September 21, 2015)*. Turtles at Bwana Said, particularly green turtles have long been exploited by these coastal communities hence need for conservation (Kakai, 2019). The landing site is remotely located with very poor accessibility hence making the site a high risk to sea turtles. On the contrary, it is the most resourceful in terms of fish landings of the three study sites.

3.4 Research design

The study used the experimental sampling in a randomized block design (Fisher, 1925; Box et al., 2005) to collect data on the effectiveness of LED lighting, which was followed by key informant interviews at the end.

A randomized block design is a type of experiment in which the experimental units are organized into blocks (boats in this case). The treatments are assigned at random to the experimental units (in this example, nets) within each block. The purpose of this design was to reduce the impact of systematic error since the experimenter focuses exclusively on the differences between treatments that eliminates the effects due to variations between the blocks. On the other hand, key informant interviews were carried out on the observers in order to gather any pertinent information. A semi-structured questionnaire was used to gather information on the demography of the study area, fishermen's knowledge of sea turtles and their conservation and LED's trials.

3.5 Sampling plan

Following Palinkas et al., (2015), purposeful sampling was employed to select the boats to be included in the study and data collection based on the commitment and history of the boats in the particular sites and fishers. The type of fishing (bottom-set gillnetting) was also a factor in the boat selection. Based on the total number (n=30) of gillnet boats present throughout the study sites for example 16 boats for Bwana Said, 8 boats for Ngomeni and 6 boats for Watamu, a sample size of 6 boats for Bwana Said, 2 boats for Ngomeni, and 2 boats for Watamu fishing sites and 10 interviewees respectively were chosen for this study.

3.6 Data collection

Data was collected in the three landing sites between December 2016 and December 2017 using 10 boats. During the study, data was collected by and from gillnet observers using data log sheets (forms) carried on daily fishing expeditions and 10 semi-structured questionnaires (Appendix 1 and 2). At the beginning of the study, selected fishermen (observers) in the three landing sites were made aware of the project, trained and later they went on to collect data on a daily basis accept on Fridays due to religious and cultural considerations. The ten boats that participated in the study, had an observer and an average of five fishermen who fished normally with their usual nets on a daily basis. At the outset of the trial, the fishing boats had their own nets which were paired (1 and 2) for the study. Group 1 nets (control) were to fish without any modification, and Group 2 nets (experimental) were fitted with gear modification/illumination (Deep Drop LED Fishing light) (Figure. 2A) placed every 15 meters along the gillnet float line. The experimental and control panels were separated by a 50-meter net where no data was collected. The gillnets were made of multifilament twine (Figure. 2B) and consisted of numerous net panels measuring averagely 50 meters in length, 3 meters in height and with their stretched-mesh sizes ranging from 6.4 cm (2.5″) to 15.2 cm (6.0″). Depending on the fishing crew, the number of gillnet panels placed each evening varied, but on average, 5 panels were set per night. Typically, nets were deployed in the late afternoon, wet overnight, and collected the next morning. Both the control and lighted nets were configured for each deployment before each boat/observer resumed their normal fishing operations, fishing in the same locations and for the same amount of time as before to record all catch and by-catch data.

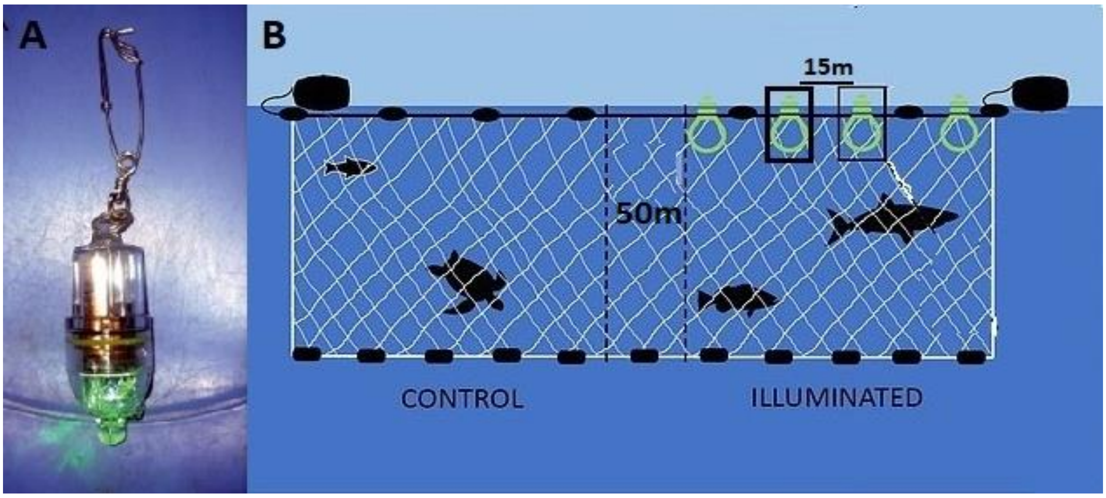

Figure 2. (A) A photo of the LED lights used during the study. (B) LED lights fitted on a bottom-set gillnet.

The observers divided the catch from the nets into three categories: target species (fish sold), bycatch (discarded fish/other species), and other (catch kept by the fishermen for consumption or retained for bait in other unrelated fisheries). The number of turtles trapped in the nets, their species, the length of their curved carapace (CCL; notch to tip (cm)), and their fate were all recorded. The carapacelength (CL) and carapace width (CW) of turtles were measured to the nearest 1.0 cm usingflexible tape measure. Internationally accepted standards were followed when releasing live sea turtles (Epperly et al., 2004; Watson et al., 2005) and to establish recapture rates, sea turtles were fitted with plastic flipper tags before being released from the nets.

Data on gear design, fishing method and operation, target fish catch composition, and weight were also collected. On each sampling occasion, fish samples were taken from the two groups of fishing nets after landing using a standard bowl. Weights of fish samples were taken at the landing beach using a top pan balance. The total fish catch from each boat was determined in kilograms. Fish were sorted separately and identified to their family and species using identification manual FAO fish identification guides by Anam, R. and Mostarda, E. (2012). Fish was measured for total length (TL) using measuring board or tape measure, and body weight (BW) with a 10 kg capacity scale.

The observers were interviewed, particularly to determine the effectiveness of the LED lights in reducing sea turtle bycatch. A semi-structured questionnaire (Appendix I) was used to gather information on the demography of the study area, fishermen's knowledge of sea turtles, their conservation status and the LED trials using interviews with the 10 study observers from in December, 2017.

The lead researcher would take part in LED trial monitoring 2 days every month to ensure correctness of the experiment. Support items (free LEDs) were provided at the end of the study to the study boats and the observers to keep their interest in the study alive.

3.7 Data analysis

Turtle and fish Catch per Unit Effort (CPUE) of the experimental nets was calculated using Wang et al. (2013) equation below:

$$\text{CPUE} = \frac{\text{Number of sea turtles caught or weight (kg) of fish caught}}{(\text{Net Length }/100\text{ m}) \text{ x } (\text{net soak time}/24\text{h})} \text{ x } 100$$

The mean catch per unit effort (CPUE) for both nets were compared using a t-test to determine statistical differences between them. In addition, paired 2-sample t-tests was utilized to compare the differences between the control and illuminated nets for sea turtles and target fish.

The composition number percentage of turtle and fish species was determined as the ratio of the number of turtle or fish species to the total number of turtles or fish caught multiplied by 100, as given below:

$$\text{Percentage composition (Nos)} = \frac{\text{Number of turtles or fish species}}{\text{Total number of turtles or fish species}} \text{ x } 100$$

Fish catch for all the species caught in the study were grouped into their respective families and their weights determined. The family composition percentage of each family was determined as the ratio of the weight of fish of a family to the weight of the total catch multiplied by 100 as given below:

$$\text{Percentage composition (Family)} = \frac{\text{Weight of fish of family (Kg)}}{\text{Weight of total catch}} \text{ x } 100$$

Length and occurrence distributions for the most common sea turtle and fish species from gillnets were analyzed at 1cm class intervals. Length and weights of all sea turtles captured and target species caught were estimated directly from length and weight values recorded and used to generate a length and weight relationship for the turtles.

The diversity of sea turtles and fish caught by the LED and non-LED nets was determined using the Shannon-Weaver index (H'), given as $H' = -\sum_{i=1}^{s} Pi(lnPi)$, where s is the number of species in the community and Pi is the proportion of individuals belonging to the species in the community (Shannon & Weaver, 1963).

The randomization test was used to assess the capture data and test the null hypothesis that there was no difference between the experimental and control nets in terms of sea turtle catch rate and CPUE. RESAMPLING STATS (v. 4.0) for Excel was used to re-sample the data numerous times. Instead of estimating significance at a certain level, this study assessed the strength of evidence against the null hypothesis.

3.8 Ethical consideration

Before beginning the investigation, a number of ethical concerns were addressed. Informed consent, acceptance, confidentiality, and anonymity of study participants were among them. The principle of informed consent was given the attention it deserved by explaining the study's purpose to participants and ensuring that they understood that participation in the study was voluntary and that they had the option of not answering any questions they did not want to answer or not participating in any way. No disclosure of personal information gained from participants during research was made after the study or throughout the analysis and subsequent drafting of this thesis, in acknowledgment of the ethical imperative that personal information obtained from participants during research be kept confidential. The study was carried out with the approval of the Kenya Fisheries Department, the Kenya Wildlife Service, and the Pwani University Ethics Review Committee, and in accordance with their licenses and ethical requirements. The study was also granted approval by the Beach Management Units Offices at the study's target locations. The study stakeholders, including fisherman in the study area, were also given disclosure and study summary reports.

CHAPTER FOUR

4.0 RESULTS

4.1 Introduction

The results of the analyses are presented in this chapter in accordance with the study's goal and objectives. The first section of the chapter reports on the effort put in by responders, while the following sections report on the study's bycatch and target catch of sea turtles.

4.2 Fishing effort

On each trip, 10 boats with an average of 5 fishers per boat fished with paired control and experimental nets for 6 days in a week. Because panels were sometimes added to maximize target species catch or were detached for repair, the number of panels in each net varied slightly between boats and across trips. As a result, just like in Wang et al., (2013), the mean length of the nets varied, with control nets averaging 0.62 km ± 0.03 SE and lit nets averaging 0.60 km ± 0.02 SE. Control nets were soaked for an average of 17.10 hours ± 0.39 SE, while experimental nets were soaked for an average of 17.40 hours ± 0.39 SE. Control nets had a mean fishing effort of 0.41 ± 0.02 SE (km x 24 hours), while lit nets had a mean fishing effort of 0.40 ± 0.01 SE (km x 24 hours) (Table 1).

Table 1. Fishing effort (Mean ± SE and range) by net type (control = without LED illumination, illuminated = with LED illumination) for paired gillnet sets in the study area.

Net type	Sets	Set duration (hr)		Net length (km)		Fishing effort (km x 24 hr)	
		Mean ± SE	Range	Mean ± SE	Range	Mean ± SE	Range
Control	80	17.10 ± 0.39	2.83-24.07	0.62 ± 0.03	0.32-1.28	0.41 ± 0.02	0.07-1.10
Illuminated	80	17.40 ± 0.39	3.75-24.33	0.60 ± 0.02	0.32-1.15	0.40 ± 0.01	0.09-0.75

Table 2. and 3. illustrates that there were 56 turtles caught in the control nets and 31 turtles caught in the illuminated nets. On the other hand, control nets caught 695 target fish (8371 kg) with a (mean ± SE) CPUE of 10.62 ± 0.71 (Km x 24 hr), while experimental nets caught 603 target fish (8517 kg) with a (mean ± SE) CPUE of 10.35 ± 0.86 (Km x 24 hr), which was statistically similar because it was not significantly affected by the presence of LEDs (P = 0.78).

Table 2. Target species and sea turtles by net type (control = without LED illumination, illuminated = with LED illumination) in the study area.

Net type	Sets	Total effort (Km x 24 hr)	Target species Caught (Individuals)	Turtles caught (Number)
Control	80	49.98	695	56
Illuminated	80	48.72	603	31

Figure 3. shows that non-LED gillnets caught sea turtles in 11 of the 12 months studied with July having the highest number of sea turtles captured (n=21), while LED gillnets trapped the sea turtles in 8 months, with may having the highest number of sea turtles(n=7) during the same period.

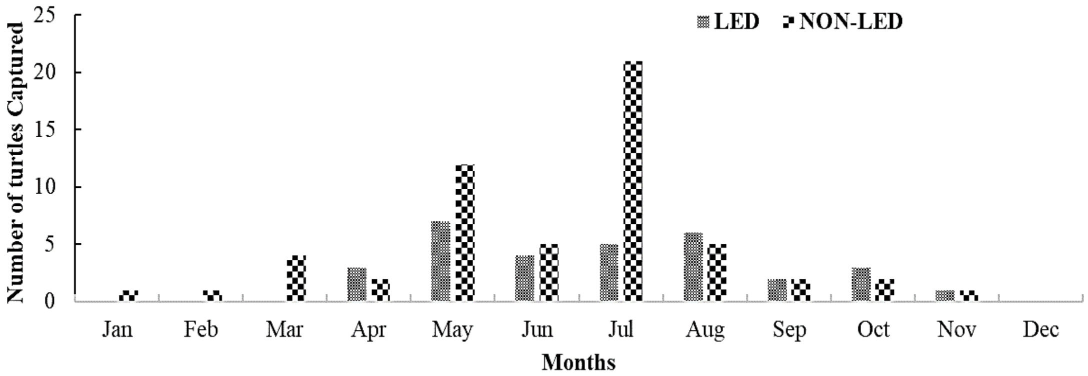

Figure 3. Monthly sea turtles caught in LED and non-LED gillnets during the study period

Analysis of the pooled data from the two sets of gillnets found the sea turtles mean CPUE values to be significant hence substantially greater in control gillnets (mean ± SE) CPUE = 1.40 ± 0.016 (Km x 24 hr) than in experimental nets (mean ± SE) CPUE = 0.50 ± 0.06 (Km x 24 hr), indicating a 64.3 % reduction in mean catch rate ($p<0.05$), (Table 3.).

Table 3. Catch per unit effort (Mean ± SE) of target species and sea turtles (control = net without LED illumination, illuminated = net with LED illumination).

Response variable	Mean CPUE Control (mean ± SE)	Mean CPUE Illuminated (mean ±SE)	% diff.	p
Target Species	10.62 ± 0.71	10.35 ± 0.86	-2.5	0.78
Sea turtles	1.40 ± 0.16	0.50 ± 0.06	-64.28	0.04

In all areas, the effort in terms of number of fish records was higher for the NEM than for the SEM. A total of 44 and 36 fishing trips were undertaken in the dry northeast monsoon season (NEM; October to March) and the wet southeast monsoon season (SEM; April to September), respectively.

4.3 Sea turtle bycatch in the bottom-set gillnets

4.3.1 Species composition

Eighty-seven turtles of four species, green (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*), loggerhead (*Caretta caretta*) and olive ridley (*Lepidochelys olivacea*), were captured during the experiment from December 2016 to December 2017. Of these, 63 were green turtles, 14 were hawksbill turtles, 9 were loggerhead turtles and 1 was an Olive ridley turtle, representing 72.4%, 16.1 %, 10.3 %, and 1.5 % respectively of the total captures (Figure 4). All turtles captured were females except two green turtles that were male.

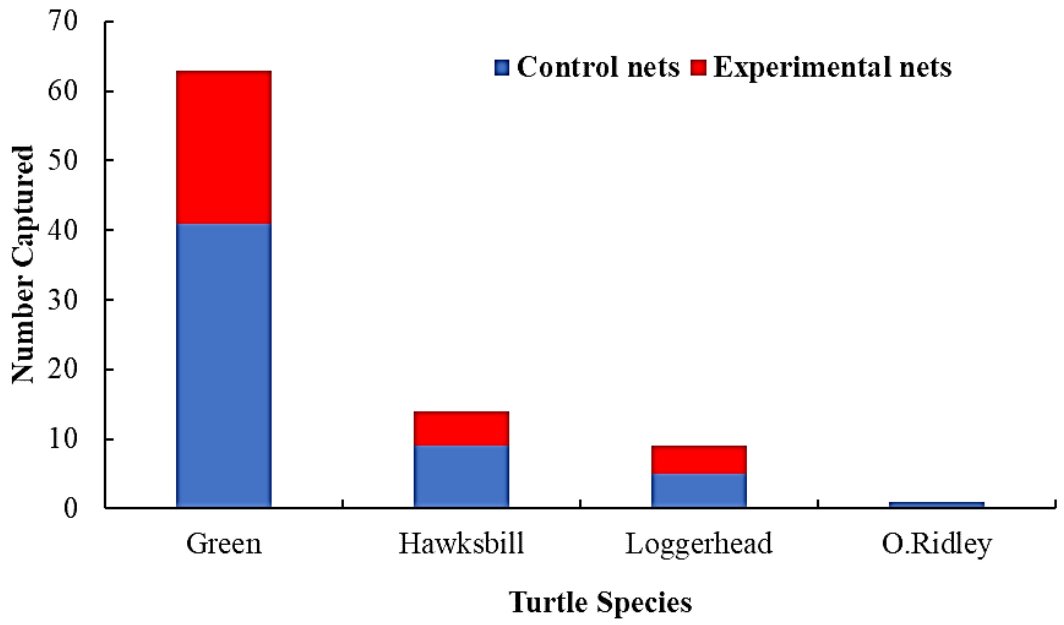

Figure 4. Numbers of each turtle species captured in different gillnets between December 2016 and December 2017.

4.3.2 Size distribution

The sizes of sea turtles captured in gillnet experiments are presented in Table 4. Average lengths of 58.0±8.5 cm, 68.7±10.2 cm, 105.3±13.4 cm and 62.4±00.0 cm were recorded for green, hawksbill, loggerhead, and olive ridleys with estimated weights of, 145.5±32.5 kg, 74.5±10.5, 132.3±23.5 kg and 46±00.0 kg respectively.

Table 4. Size of sea turtles captured in bottom set gillnets from December 2016 to December 2017

		Carapace length (cm)		Carapace width (cm)		Estimated Body weight (kg)	
Species	**N**	Min - Max	Mean ± SE	Min -Max	Mean ± SE	Min -Max	Mean ± SE
Green turtles	63	31.7 - 81.0	58.0±8.5	37.2 - 70.5	51.9±20.5	78.0 - 212.5	145.5±32.5
Hawksbill	14	58.5 - 82.0	68.7±10.2	45.5 - 68.0	56.0±8.0	52.5 - 98.3	74.5±10.5
Loggerhead	9	110.5 - 138.0	105.3±13.4	98.5 - 118.0	106.0±6.1	112.5 - 158.3	132.3±23.5
Olive ridley	1	62.4	-	53	-	46	-

4.3.3 Length-frequency distribution

Figure 5. shows the length frequency distribution of sea turtles caught in both gillnets during the study period. The carapace length of turtles fell within the size class of 71-80 cm. The modal class size was 71-80 cm.

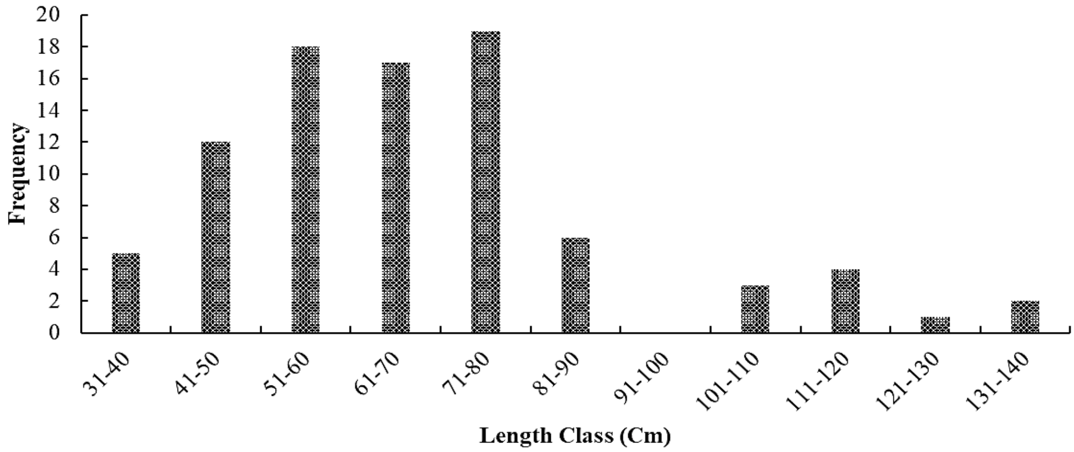

Figure 5. Length-frequency distribution of sea turtles caught in gillnets during the experiments.

4.3.4 Monthly variation in abundance

Variations in the number of turtles caught in the gillnets during the study period are shown in Figure 6. Green sea turtles were caught from March to November, hawksbills were caught from February to August and loggerhead were caught from May to September. Only one Olive ridleys was caught in January of the study period. Generally, sea turtles capture during the months was sporadic.

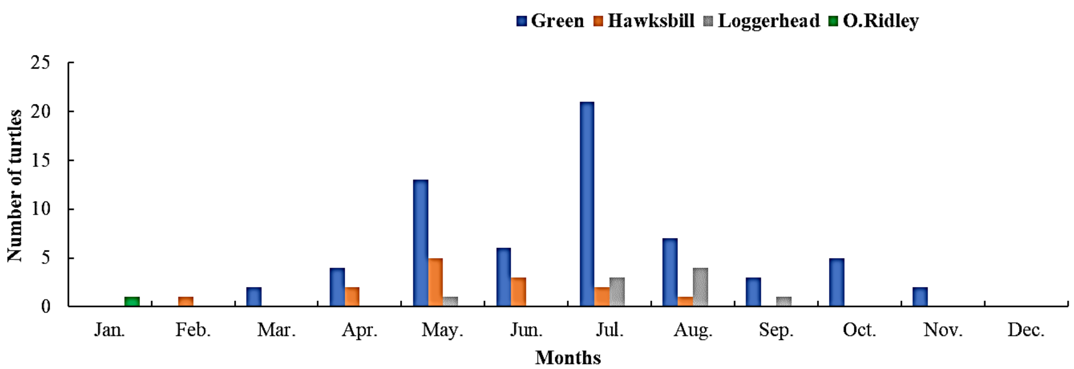

Figure 6. Monthly number of sea turtles captured in gillnet experiments.

4.4 Turtles caught in LED and non-LED gillnets

4.4.1 Species composition

Thirty-one sea turtles as shown by table 5. were captured in nets fitted with LEDs which comprised, 22 green turtles, 5 hawksbill, and 4 loggerhead. All turtles captured were females. On the other hand, fifty-six sea turtles from four species, namely green (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*), loggerhead (*Caretta caretta*) and olive ridley (*Lepidochelys olivacea*), were captured during the bottom-set gillnet experiments from December 2016 to December 2017 by the gillnets without LED lights (Table 6.). They comprised 41 green, 9 hawksbills, 5 loggerheads, and 1 olive ridley. All the sea turtles captured were females except two green turtles that were male.

4.4.2 Size distribution

The sizes of sea turtles captured in gillnets fitted with LEDs are presented in Table 5. The green sea turtles measured 31.7.0 cm to 75.0 cm, hawksbill 58.5 to 81.0 cm and loggerhead 110.5 to 128.0 cm in carapace length while on the other hand their carapace width was 35.2 cm to 65.5 cm, 43.5 to 65.0 cm and 88.5 to 110.0 cm respectively.

Table 5. Mean size of sea turtles captured in gillnets with LED

		Carapace length (cm)		**Carapace width (cm)**		**Estimated Body weight (kg)**	
Species	N	Min - Max	Mean ± SE	Min -Max	Mean ± SE	Min -Max	Mean ± SE
Green turtles	22	31.7 - 75.0	54.0±6.5	35.2 - 65.5	50.9±10.5	78.0 - 202.5	143.5±30.5
Hawksbill	5	58.5 - 81.0	66.7±10.2	43.5 - 65.0	54.0±8.0	52.5 - 95.3	74.3±10.5
Loggerhead	4	110.5 - 128.0	108.3±12.4	88.5 - 110.0	108.0±5.2	122.5 - 158.3	133.3±20.5

The sizes of sea turtles captured in gillnets without LED are shown in Table 6. Average lengths of 31.9±82.4 cm, 60.5±80.0 cm, 112.5±138.0 cm and 62.4±00.0 cm were recorded for green sea turtles, hawksbill, loggerhead and olive ridleys with estimated weights of 144.5±30.5 kg, 74.4±10.4 kg, 130.3±26.5 kg and 46±00.0 kg respectively.

Table 6. Mean size of sea turtles captured in gillnets without LED.

Species	N	Carapace length (cm)		Carapace width (cm)		Estimated Body weight (kg)	
		Min - Max	Mean ± SE	Min -Max	Mean ± SE	Min -Max	Mean ± SE
Green turtles	41	31.9 - 82.4	68.0±8.4	38.2 - 72.5	52.9±20.5	88.0 - 212.5	144.5±30.5
Hawksbill	9	60.5 - 80.0	66.7±9.2	47.5 - 68.0	57.0±8.0	54.5 - 98.3	74.4±10.4
Loggerhead	5	112.5 - 138.0	106.3±13.4	96.5 - 118.0	104.0±5.1	112.5 - 154.5	130.3±26.5
Olive ridley	1	62.4	-	53	-	46	-

4.5 Fish catch in the bottom-set gillnets

The targeted fish species caught in the experimental bottom-set gillnets between December 2016 and December 2017 is shown in Table 7. The LED gillnets caught 48 fish species belonging to 29 families, while the non-LED nets caught 49 species belonging to 27 families.

Family	Species	Common Name	LED	Non-LEDs
Acanthuridae	*Acanthurus chronixis*	Chronixis surgeonfish	+	+
Aetobatidae	*Aetobatus narinari*	Spotted eagle ray	-	+
Albulidae	*Albula glossodonta*	Roundjaw bonefish	-	+
Ariidae	*Plicofollis dussumeiri*	Blacktip sea catfish	+	+
Belonidae	*Strongylura incisa*	Reef needlefish	+	+
	Tylosurus crocodilus	Hound needlefish	+	+
Carangidae	*Scomberoides commersonianus*	Talang queenfish	+	+
	Carangoides ferdau	Blue trevally	+	+
	Caranx sexfasciatus	Bigeye trevally	+	+
	Carangoides fulvoguttatus	Yellowspotted trevally	-	+
	Caranx tille	Tille trevally	+	-
Chanidae	*Chanos chanos*	Milkfish	+	+
Dasyatidae	*Himantura uarnak*	Honeycomb stingray	+	+
Ephippidae	*Platax orbicularis*	Orbicular batfish	+	+
Gerreidae	*Gerres longirostris*	Strongspine silver-biddy	+	+
	Gerres oyena	Common silver-biddy	+	-
Haemulidae	*Plectorhinchus flavomaculatus*	Lemonfish	+	-
	Plectorhinchus gaterinus	Blackspotted rubberlip	-	+
	Plectorhincus playfairi	Whitebarred rubberlip	+	+
Hemiramphidae	*Hyporhamphus affinis*	Tropical halfbeak	+	+
Holocentridae	*Myripristris berndti*	Blotcheye soldierfish	+	+
Labridae	*Anampses caeruleopunctatus*	Bluespotted wrasse	-	+
	Cheilinus chlorourus	Floral wrasse	+	+
	Coris formosa	Queen coris	+	+
Lepisosteidae	*Lepisosteus oculatus*	Spotted gar	+	-
Lethrinidae	*Lethrinus nebulosus*	Spangled emperor	+	+
	Lethrinus lentjan	Pink ear emperor	+	+
	Lethrinus harak	Thumbprint emperor	+	+
	Lethrinus mahsena	Sky emperor	+	+
	Lethrinus miniatus	Trumpet emperor	+	+
	Lethrinus borbonicus	Snubnose emperor	+	+
Lutjanidae	*Lutjanus fulviflamma*	Dory snapper	+	+
	Lutjanus argentimaculatus	Mangrove red snapper	+	+
Mugilidae	*Mugil cephalus*	Flathead grey mullet	+	+
	Valamugil seheli	Bluespot mullet	+	+
Mullidae	*Parupeneus barberinus*	Dash-and-dot goatfish	+	+
	Parupeneus cyclostomus	Gold-saddle goatfish	+	+
	Parupeneus macronema	Long-barbel goatfish	-	+
Myliobatidae	*Manta birostris*	Giant manta ray	+	-
Plotosidae	*Paraplotosus albilabrus*	Whitelipped eel catfish	+	+
Rachycentridae	*Rachycentron canadum*	Cobia	+	+
Rhinidae	*Rhynchobatus djiddensis*	Giant guitarfish	+	+
Scaridae	*Leptoscarus vaigiensis*	Marbled parrotfish	+	+
	Scarus rubroviolaceus	Ember parrotfish	+	-
	Scarus ghobban	Blue-barred parrotfish	+	-
	Calotomus carolinus	Carolines parrotfish	-	+
Scombridae	*Euthynnus affinis*	Mackerel tuna	+	+
	Scomberomorus commersoni	Narrow-barred Spanish mackerel	+	+
	Scomberomorus plurilineatus	Kanadi kingfish	+	+
	Thunnus albacares	Yellowfin tuna	-	+
	Katsuwonus pelamis	Skipjack tuna	+	+
Serranidae	*Epinephelus fuscoguttatus*	Brown-marbled grouper	+	+
	Epinephelus lanceolatus	Giant grouper	+	+
Siganidae	*Siganus sutor*	African whitespotted rabbitfish	-	+
Sphyraenidae	*Sphyraena barracuda*	Great barracuda	+	-
Sphyrnidae	*Sphyrna lewini*	Scalloped hammerhead	+	+
Xiphiidae	*Xiphias gladius*	Swordfish	+	+
TOTAL SPECIES PRESENT			**48**	**49**

Table 7. Fish species targeted during the experimental fishing with LED and non-LED gillnets during the study. '+' and '-' indicate species present and absent respectively

Figure 7 illustrates the percentage composition of common fish species caught by gillnets with LEDs and gillnets without LEDs. *Siganus sutor* was the most abundant with composition of 43.6% and 41.9% of the total catch from LED and non-LED gillnets, respectively. *Lutjanus fulviflamma* had the second highest composition forming 29.9% of the total catch in LED and

31.8% of the total catch in non-LED gillnets. Coming in third place was *Lethrinus harak* which had a composition of 14.5% of the total catch in LED and 13.4% of the total catch in non-LED gillnets. *Euthynnus affinis, Scomberomorus commersoni, Coryphaena hippurus, Himantura uarnak, Carcharhinus melanopterus* and *Taeniura lymma* were all lowly represented in the catches with compositions less than 10% for LED nets and non-LED gillnets.

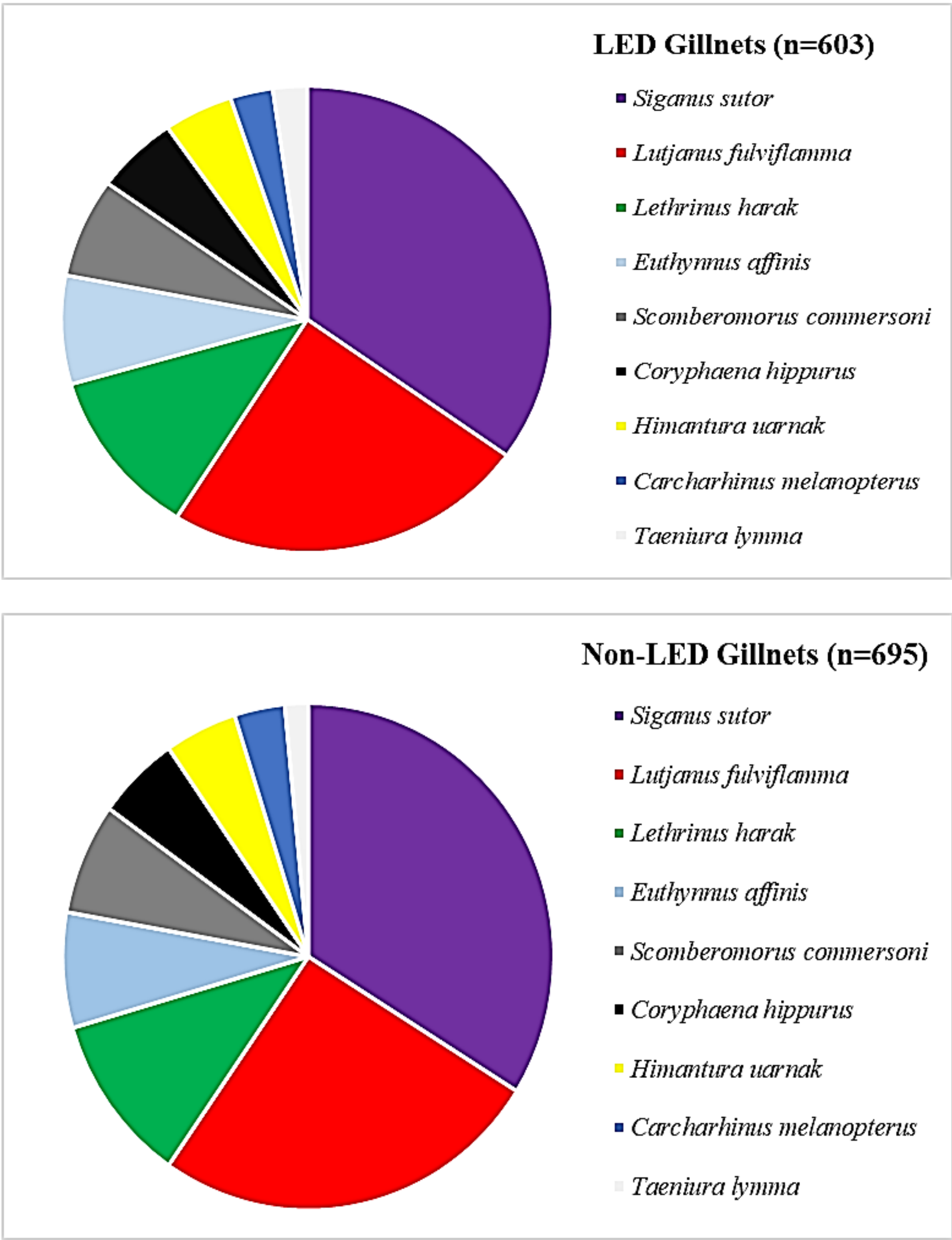

Figure 7. Percentage composition of fish species caught by LED and non-LED gillnets.

The diversity indices of fish caught in the two groups of gillnets was observed from the values provided in tabled 8. that indicates there is no significant difference in the diversity of fish caught in the LED and non-LED gillnets. The LED gillnets caught 48 fish species belonging to 29 families, while the non-LED nets caught 49 species belonging to 27 families.

Table 8. Diversity indices of fish species caught by LED and non-LED gillnets

	Number		**Richness**	**Diversity**	**Evenness**
Treatment	**Families**	**Species (*s*)**	**(*d*)**	**(*H'*)**	**(*J'*)**
LED gillnets	29	48	4.12	1.86	0.42
Non-LED gillnets	27	49	4.08	1.98	0.46

4.5.1 Monthly fish catch variation in the gillnets

Figure 8 illustrates monthly variations in fish catch in LED and non-LED gillnets. The monthly fish catch for LED gillnets was highest in February 2017 (n=1514 kg) and lowest in May 2017 (n=198 kg). The highest fish catch for the non-LED gillnets was recorded in January 2017 (n=1301 kg) and the lowest catch was recorded in June 2017 (n=113 kg). Higher catches, dominated by white-spotted rabbitfish (*Siganus sutor)*, mackerel tuna (*Euthynnus affinis)* and honeycomb stingray (*Himantura uarnak)* tended to be caught in gillnets for most months of the study period except in May, June and July 2017.

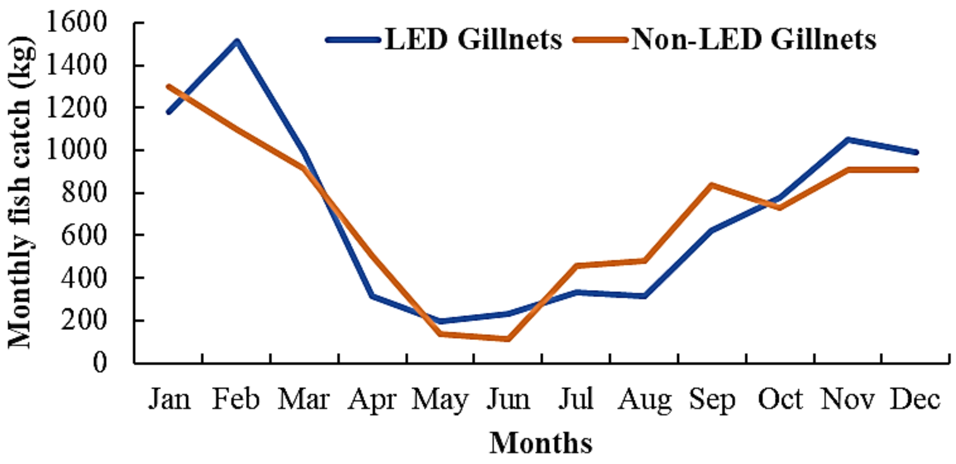

Figure 8. Monthly fish catch variations in the gillnets during the study period

4.5.2 Common fish species length-frequency distribution

Table 9 displays the length-frequency distributions of the five common fish species caught in LED and non-LED gillnets. The data for fish caught between December 2016 and December 2017 was pooled and showed a similar modal class for *Siganus sutor*, *Lutjanus fulviflamma*, *Euthynnus affinis* and *Scomberomorus commersoni* over the study period. On the other hand the size range was also similar for *Lutjanus fulviflamma* and *Lethrinus harak* over the study period.

Table 9. Common fish species length-frequency distribution in the study

Species	Size range (TL)(cm)		Modal length (cm)	
	Non-LED	LED	Non-LED	LED
Siganus sutor	24.0 - 35.0	24.0 - 36.0	30.0 - 30.9	30.0 - 30.9
Lutjanus fulviflamma	25.0 - 36.0	25.0 - 36.0	31.0 - 31.9	31.0 - 31.9
Lethrinus harak	22.0 - 44.0	22.0 - 46.0	33.0 - 33.9	32.0 - 33.9
Euthynnus affinis	42.0 - 86.0	42.0 - 86.0	64.0 - 64.9	64.0 - 64.9
Scomberomorus commersoni	88.0 - 162.0	90.0 - 162.0	125.0 - 125.9	125.0 - 125.9

4.6 Study observer's interaction with sea turtles

The 10 (100%) study observers interviewed confirmed they had good knowledge about sea turtles and their capture in gillnets. They reported encountering five species of turtles namely, green (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*), loggerhead (*Caretta caretta*) leatherback (*Dermochelys coriacea*) and olive ridley (*Lepidochelys olivacea*). All respondents categorized loggerheads as the largest turtle and olive ridley as the smallest turtles. They also all confirmed the field data that green sea turtles are the most captured in the gillnets, with a prevalence bycatch of 70 % (n=63).

In table 10 sea turtles were reported by observers to have various importance as; a food source (20%), providing income (17%), protecting fish (15%), and serving as indicators of fish presence (26%). They were also reported to be of cultural significance (41%). While 88% of respondents recognized sea turtles as important in the ocean, 12% of respondents reported sea turtles as having negative impacts like tearing nets and capsizing boats.

Table 10. Responses of observers to questions on the importance of sea turtles

Importance of sea turtles	% response
Positive Impact	
Fish protection	12
As a food source	20
Indicators of fish presence	23
Source of income	12
Cultural value	21
Negative Impact	
Destruction of Fishing nets	8
Capsizing boats	4

The most prevalent bycatch species occurring in gillnets as reported by all 10 interviewees were green turtles, with 46 % of admissions as shown in figure 9. Hawksbills, Olive ridleys, loggerheads and leatherbacks were the species also sighted and captured in the study area with incidence rates of 24%, 16%, 8%, and 6% bycatch respectively.

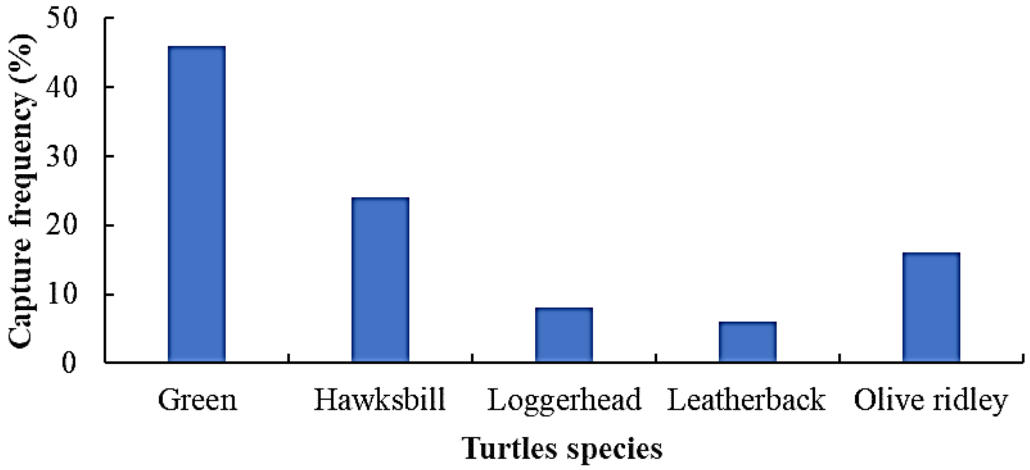

Figure 9. Frequency percentage of sea turtle species capture in gillnets.

A hundred percent of the interviewees indicated they caught sea turtles in their gillnets as shown in figure 10 with 70% of the respondents catching between 1 and 10 sea turtles annually and the rest 30% of the interviewed observers capturing more than 11 sea turtles every year in their gillnets.

The results also indicated that most captures of sea turtles occurred from April to July which was in line with the field data.

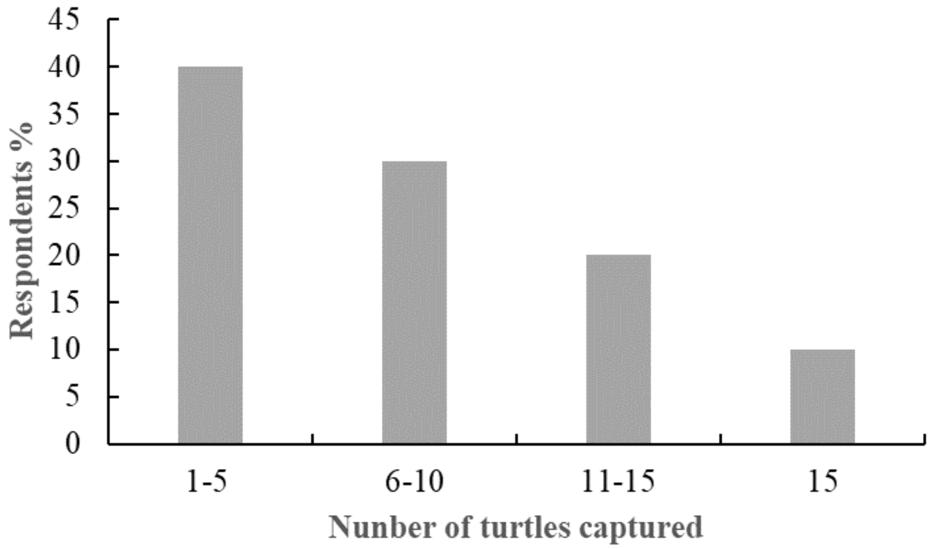

Figure 10. The number of sea turtles captured in gillnets per year by interviewees

The 10 interviewees reported that sea turtles captured were usually alive and active when removed from fishing nets while 20% mentioned that the turtles were usually dead before releasing them into the sea or taking them away for food. They also reported that turtles captured alive in fishing nets were either killed for food (45%), sold for money (17%), or released (38%). All of the interviewees acknowledged experimenting with LEDs, having used them 65% of their operations but, cited issues of bad weather, not charged LEDs, and damaged nets among other reasons for not using them all the time. Sixty percent of the observers reported LEDs reduced sea turtle bycatch, 30 % said they increased target catch while 10% were not sure either way which confirms the filed data.

CHAPTER FIVE

5.0 DISCUSSION

5.1 Introduction

The chapter discusses the results as related to artisanal fishery and sea turtle bycatch in this study, the rate of target fish catch and sea turtle by-catch in gillnets and the effectiveness of light emitting diode (LED) on sea turtle and fish catch in the artisanal fishery in the study area. It also gives recommendations.

5.2 The artisanal fishery in the study area

The presence of marine artisanal fishery in the study area between December 2016 and December 2017 is in line with those made by Frazier (1975) and the Government of Kenya (2014) who reported high trends in the artisanal number of fishery vessels and gillnets in Kenya's coast and the study area. Kimani et al. (2015) also reported that the effort in the marine artisanal fishery of the country has been increasing for some time now, which is verified by this study. The general high number of fishermen and vessels in the study area could be due to the high population in the area resulting in more people going into the artisanal fishing industry or due to migrant fishers. The Commission on Revenue Allocation, CRA (2020) reported that population growth in coastal Kenya had resulted in a high number of coastal people engaged in marine artisanal fishing.

Similarly, the population of Watamu and Ngomeni, some of the study sites was reported to have increased in 2020 (Commission on Revenue Allocation, 2020) with each artisanal fisherman estimated to have between one and three wives and 74% of the fishermen also having four or more children (KNBS, 2019), it is likely that the population growth in the study area is higher in the fishing communities than the non-fishing communities. Over 80% of children belonging to fish dealers in the Kilifi County coastal area are reported to have a low level of education (KNBS, 2019). Thus, the children in the study area tend to join the fishing, processing, or trading of fish like their parents increasing the population of fishermen in the study area as was reported during interviews in this study.

The higher number of artisanal fishermen and gillnets existed as a result of an informal agreement between the Fisheries department office in the area and Kenya wildlife Service whereby vessels that are not registered were not allowed to access fishing grounds. The majority of the boats that still do not have licenses were those that mainly use oars and sails during fishing.

The number of fish species and families reported in the present study area is lower than those reported by the Government of Kenya (2014) which sampled more fish species in the study area. The difference in the number of species and families observed in the two studies could be attributed to the various abilities as well as sampling design and methods used.

The annual declining catch in the area could be attributed to the declining stocks of small pelagic and demersal which represented the bulk of the catch in the artisanal bottom-set gillnet fishery (Kimani et al., 2014). This observed decline in small pelagic stocks has been reported by other authors as well. Osuka et al., (2021) recounted a rapid decline in small pelagic landings between 2014 and 2015 and remarked that the small pelagic resources are on the verge of collapse.

The decline in catches of small pelagic in Kenya has been attributed to many factors. Obura (2001) and Kimani et al. (2018) attributed the drastic decline in the trend of fish catch mainly to overfishing and overcapacity of fishing fleets as well as the use of smaller mesh sizes in fishing.

Overfishing causes changes in species composition and abundance of both targeted and non-targeted fish and causes unpredictable changes in marine ecosystems (FAO, 2018). Other contributing factors are poor enforcement of the regulatory frameworks and insufficient monitoring and surveillance of Kenya’s coastal waters which have resulted in more vessels entering the fishery with the tendency of over-burdening the situation in the marine fishery sector (Munga et al., 2012).

Contrary to reported increases in fishing efforts by vessels (McClanahan and Mangi, 2004), a decline in fishing efforts by the number of days spent at sea (280 days) was recorded in the study area. The fewer days spent at sea by fishermen were mainly a result of the low fish catch being experienced in the artisanal fishery of the area, as also observed by Kimani et al., (2018) in Kilifi coastal fishing grounds. The lack of fishing inputs such as gillnets and outboard motors, lack of motivation due to low catches and bad weather could also be contributing factors to the low number of fishing days recorded for fishermen in the study area.

The fish species recorded in the study area were dominantly demersal, *Siganus sutor* which formed 43.90% of the total catch by weight, *Lutjanus fulviflamma* constituting 31.80% and *Lethrinus harak* constituting 14.50% of the total catch landed between December 2016 and December 2017. Other species recorded low catches over the same period.

Osuka (2021) also asserted that the demersal and some pelagic fishes, such as *Euthynnus affinis, Scomberomorus commersoni, Coryphaena hippurus, Himantura uarnak, Carcharhinus melanopterus and Taeniura lymma* were all lowly represented in the catches with compositions less than 10%, were the main stocks that form the backbone of Kenya's artisanal fishery, and their abundance strongly dependents on the intensity of seasons.

Catches of *Siganus sutor* and *Lutjanus fulviflamma* were high in January and February in the study period. This high catch recorded could be due to the upwelling and calmness of the sea hence high CPUE which also occurred in the months of September to December, with a weaker intensity (Fondo, 2004).

5.3 The sea turtle incidence in the artisanal fishery

In reference to the study 87 sea turtles of four species, green (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*), loggerhead (*Caretta caretta*) and olive ridley (*Lepidochelys olivacea*), were captured during the experiment from December 2016 to December 2017. Of these, 63 were green turtles, 14 were hawksbill turtles, 9 were loggerhead turtles and 1 was an Olive ridley turtle, representing 72.4%, 16.1 %, 10.3 %, and 1.5 % respectively of the total captures (Figure 4). All turtles captured were females except two green turtles that were male.

The olive ridley and leatherback were rarely captured. The relatively high occurrence of these three species (63 green, 14 hawksbill and 1 olive ridley turtles) reported by observers could be due to the fact that these are the species that nest on the study beaches while the loggerhead and leatherback only utilize the coastal waters of Kenya for feeding and migration (Frazier, 1975; Wamukoya et al., 1997; Okwema et al., 2004, Kakai, 2019).

The capture of sea turtles in fishing nets was accidental, as reported by all the interviewees but at times culture and monetary value dictate their capture. Other similar studies have also reported fishermen acknowledging that the capture of sea turtles in their fishing nets was accidental (Spotila et al., 2000; Olendo et al., 2017; Alexander, et al., 2017). Fishermen have on many occasions disrupted sea turtles swimming toward their nets, by creating noise that causes the turtles to dive deeper and away from the fishing nets. Such noise could perhaps mimic those from acoustic pingers by emitting sounds to scare the turtles away. Such devices as LED and pingers are devices that prevent marine life such as sea turtles, sharks and dolphins from interacting with and getting caught in fishing nets (Wang et al., 2013; Barkan, 2010).

Fishermen do not target sea turtles during fishing operations for many reasons but they mainly avoid catching sea turtles to protect their nets from getting destroyed and fish loss (Wamukota and Okwema, 2009; Agyekumhene et al., 2014; Olendo et al., 2017). Some fishermen also avoid turtles in their nets for reasons such as avoiding punishment from the law, as also reported by Kakai, (2019). Kenyans Wildlife Conservation Act of 2013 also, prohibits hunting, capturing and killing of sea turtles. The role of sea turtles in the health of the ocean makes them a non-target species for fishermen in most cases as recorded in the study interviews. For some of the interviewees, sea turtles have cultural values and have to be protected for that reason. Fishermen however reported the diminishing effect of traditions as a result of intermarriage with people from other tribes who do not share the belief and migrant fishers from other communities into the study area (Kakai, 2019). This study revealed and recommended that conservation education is key and important in conserving species in local communities.

Sea turtles are eaten as food, sold for money, or released back to sea when captured as the study shows in table 9. The fishermen who sold sea turtles did so to raise money to defray some of the cost of repairing their fishing nets (Okwema et al., 2004). With most families in Kenya's coastal fishing communities living on an annual income below the national average (CRA, 2020), damage to fishing nets or loss of a vessel can be a huge source of financial burden to a fisher. Turtles were at times sold by fishers because of the decline in fish stocks which has greatly increased the pressure on turtle meat as an alternative income and food source (Olendo et al., 2017) as reported by the interviews. In spite of the destruction sea turtles cause to the nets of fishermen and the economic loss associated, e.g., loss of fish and nets, fishermen still perceive sea turtles as important.

5.4 The capture rate of sea turtles in artisanal bottom-set gillnets

The sea turtle species encountered in this study are similar to what has been reported by other authors in other areas along the coast of Kenya (Frazier, 1997, Okwema et al., 2004, Wamukota and Okwema 2009, Olendo et al., 2017 and Kakai, 2019). The relatively higher numbers of green sea turtles encountered in this study (Figures 4, 6, and table 4, 5, 6) suggest that they are the commonest species in Kenya's coastal waters. This finding validates those of Frazier et al. (1975), and Okwema et al., (2004).

All species combined, the mean capture rate of sea turtles per boat and fisher per year recorded by the 10 observers in the study period was more or less the same as numbers reported by observers in the interviews in which 70% claimed to catch up to 10 turtles in a year. Although the sea turtle bycatch per fisher appears to be low, the collective impact of the captures in the entire fishery of the Kenyan coast since the gillnets are one of the most widely used gears among marine artisanal fishers in all coastal counties of Kenya, with a total of 3 835 gillnets recorded in 2016, increasing by 15% from 2014 (Government of Kenya 2016). With over 1110 gillnets used in the study area (Government of Kenya, 2016), the capture of sea turtles is estimated to be over 150 turtles per year, as also estimated by Watamu Turtle Watch (2014) and this could have a huge impact on the population of the species.

Except for two male green sea turtles, every one of the 87 turtles that were caught was a female. Only female turtles swim closer to the coastline and have a tendency to congregate in near-shore locations, especially during inter-nesting intervals, which accounts for the lack of male turtles in gillnets throughout this study. Female turtles nearing nesting are reported to occupy inshore waters during the inter-nesting season and only migrate into oceanic waters outside of this period (Alvarro and Murphy, 1999).

Green sea turtles have been reported to nest in Kenya (Frazier, 1975; Wamukoya, 1997; Okwema et al., 2004; Kakai, 2019) which could be the reason for their capture in all the months, except January, February and December. The higher number of sea turtle captures in April and August could be due to the fact that in Kenya, nesting by all three species is reported to peak in Apri-June (Okwema et al., 2004, Wamukoya, 1997; Wamukota and Okwema, 2009; Olendo et al., 2017; Kakai, 2019). The large number of sea turtles caught during the prime nesting months, when inter-nesting migration occurs most frequently, is likely due to the fact that sea turtles are known to spend the majority of their time in close-to-shore locations during inter-nesting migrations. The findings made from this study on species of turtle present in the study area and the months in which they are mostly captured were similar for both the field observations and the responses given by the observers during interviews.

The smaller number of olive ridleys captured in the study (n=1) could be the result of the nesting of different populations and species in sea turtles (Frazier, 1980; Lewison et al., 2014). Also, the mean carapace length recorded for olive ridley sea turtle captured in gillnets (62.4 cm) was respectively lower than the mean length of 68.0±8.4 cm recorded for green sea turtles nesting on beaches in Kenya (Okwema et al., 2004).

5.5 The capture of sea turtles in artisanal bottom-set gillnet experiments

There was no leatherback sea turtle capture in both of the gillnets as there was no olive ridley in any of the LED nets. The absence of leatherback and olive ridley in the LED nets could be due to their relatively lower numbers encountered in Kenyan coastal waters (Wamukota and Okwema, 2009; Kakai, 2019). Even though the non-LED nets caught loggerhead sea turtles, the numbers were relatively fewer than the other species affirming the observation that loggerhead sea turtles don't nest in coastal Kenya and hence have the least abundance after olive ridley among the species that currently nest and forage in Kenya, as also reported by Frazier (1975). The absence of some sea turtle species in the gillnets with LED could also be attributed to the species being more reactive to the LED light than others. Differences in spectral sensitivities of different species of sea turtles have been reported (Southwood et al., 2008; Wang et al., 2008; Ortiz et al., 2016; Kakai, 2019; Bielli et al., 2020).

The green sea turtle was the dominant species trapped in both the non-LED and LED nets which is similar to findings made by other studies on the nesting ecology of turtles along beaches in Kenya, which reported that of all the sea turtle species in Kenya, the green sea turtle is the most abundant (Frazier, 1975; 1980; Okwema et al., 2004; Kakai, 2019). The number of turtles caught in the gillnets during the study period was lower than was expected and this could be due to the fact that different individuals and populations nested during different years among the species and it is dependent on the quality and quantity of food available for energy accumulation, deposition, reorganization and utilization (Bjorndal, 1980). Also, the fishing effort was lower since boats were left to operate normally like they used to operate at times, not fishing due to weather conditions, religious beliefs, damaged nets and not working LEDs among other reasons.

Most of the sea turtles captured in gillnets with and without LED occurred between March and October with the peak capture occurring in July 2017. This is probably due to the fact that sea turtles nest on Kenya's beaches primarily between March and August (Okwema et al., 2004; Olendo et al., 2017) and mostly migrate through the Kenyan coastal waters during this period.

The CPUE for sea turtle capture was significantly lower ($p<0.05$) in nets with the LED lights (0.50 ± 0.06 turtle/100 km net/24 hrs) than in the nets without LED lights (1.40 ± 0.016 turtle/100 km net/24 hrs). This supports the observation by Wang et al., (2008), Ortiz et al., (2016) and Kakai, (2019) that the use of green LED light is effective at reducing sea turtle capture in gillnet fishing. A similar study conducted in Baja California, Mexico by Wang et al. (2010) also revealed that green LED lights reduced sea turtle capture in gillnets by 39.7%. The use of bycatch reduction technologies has been shown by many authors and researchers to be effective at reducing sea turtle capture in most fisheries and it is becoming a growing method of interest (Melvin, Parrish and Conquest, 1999; Ortiz, 2016).

5.6 The occurrence of fish species in the artisanal bottom-set gillnets experiments

The number of species (97) and families (56) recorded in the experimental nets is less than those reported by other authors such as Osuka et al., (2021). The difference in sample size, sampling location, period, duration and effort between the two studies could account for the difference in species observed in the two areas. Bruno et al. (2013) attributes the structure and fish assemblage distribution to factors such as food availability, dissolved oxygen and turbidity, or biological interactions.

Higher fish catches were dominated by white-spotted rabbitfish (*Siganus sutor)*, mackerel tuna (*Euthynnus affinis)*, thumbprint emperor (*Lethrinus harak*) and honeycomb stingray (*Himantura uarnak)* tended to be caught in gillnets for most months of the study period except in May, June and July 2017, in both the non-LED and LED nets. These species are the most common in Kenyan artisanal marine fishery as also reported by the Government of Kenya, (2014), and Fondo et al., (2004). Osuka et al., (2021) reported the white-spotted rabbitfish (*Siganus sutor)* as one of the commonly occurring marine fish species in gillnets which were similar to the findings made in this study. The majority of the families and species were similar between the LED and non-LED gillnets. The difference in the diversity of fish caught between LED and non-LED gillnets was also low.

The absence of a significant difference in species composition of fish caught by the LED and non-LED gillnets could also imply that the LED light had no effect on fish composition though it appeared to impact the behavior of sea turtles by causing the sea turtles to avoid the gillnets. This is collaborated by the studies of Wang et al., (2010, 2013), Ortiz et al., (2016), Kakai, (2019), and Bielli et al. (2020) which concluded that using LED lights on gillnets to reduce sea turtle capture did not have any impact on target fish catch. The LED light warns only the turtles of the presence of the gillnet, thereby deterring them from entering, but the visual capacity of the fish may not allow them to perceive the gillnets and hence get captured. Although sea turtles and fish occupy the same marine habitat, their behaviors are different enough to produce responses that vary in their sensory perceptions (Southwood et al., 2008; Kakai, 2019).

There was no significant difference (p=0.78) between the total weight of fish caught by the LED and non-LED gillnets over the study period. This finding is in line with those of Wang et al. (2010, 2013 and Ortiz et al., 2016) who found that illuminating fishing nets with LED lights did not result in a significant decrease in the volume of target species (Kakai, 2019). Thus, suggestively the LED light does not influence fish catch and does not function as a fish aggregating device. The similarity in the modal class for the dominant fish species caught as shown in table 8 in the study area could be further indication that the LED light did not influence the sizes of fish caught. This further indicates the LED may not be aggregating fish hence not performing light fishing.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

This study affirmed that gillnet fishing happens in the study area and the fishing effort in the study area was increasingly going down, sea turtle bycatch in gillnets does happen, while the number of landing sites remained the same. The increasing fishing effort is a result of the population increase in the fishing communities in the study area. Gillnet artisanal fishers in the area operated different fishing gear from wooden boats/canoes powered by 5 hp to 40 hp outboard motors or sail. The bottom-set gillnets were the dominant gear type in the study area.

From December 2016 to December 2017, 97 fish species from 56 families were recorded from the artisanal gillnet fishery in the study area. Demersal and small pelagic fish species were the most common ones found in the artisanal gillnet fisheries of the study area. There was a downward trend in catches of fish species by the artisanal gillnet fisheries of the area as a result of overfishing, overcapacity and an increased number of fishermen and fishing boats in the area. Fish species catches dominated by white-spotted rabbitfish (*Siganus sutor*), mackerel tuna (*Euthynnus affinis*), thumbprint emperor (*Lethrinus harak*) and honeycomb stingray (*Himantura uarnak*) tended to be caught most in the artisanal gillnets of the study area. Most fishers and observers did not go to sea as often as they used to due to the low and sometimes zero catch, which resulted in the reduced number of fishing days in the area, hence low catches. The catches of turtles in LED and non-LED gillnets were similar. Although five species of sea turtles occur in the coastal waters of the study area for nesting and foraging habitat, only four (green sea turtles, hawksbill, loggerhead and Olive ridley) were captured in fishing gillnets during the study period. Of the total captures, the green sea turtles (72.4%) were the most dominant followed by the hawksbill (16.1%), loggerhead (10.3) and olive ridley sea turtles (1.5%).

The capture of sea turtles happened in the study area at a rate of 8.7 turtles per boat per year. Though green sea turtles were caught in bottom-set gillnets year-round, sea turtle capture in fishing nets occurred mainly from March to August peaking in May to July.

The sea turtle number caught in fishing nets using LED lights was low (n=31) but high in nets without LED lights (56 turtles). CPUE for sea turtle capture was significantly lower in gillnets using LED lights than in nets without LED lights. Using the LED lights on gillnets for fishing, therefore, resulted in a reduction in sea turtle bycatch.

The use of LED light was not found to impact the total quantity of fish families and species caught in gillnets since they were similar between the LED and non-LED gillnets.

The study found that any device that reduces sea turtle bycatch should be effective, easy to deploy, not costly and must not present a huge modification to gillnets such that it interferes with the deployment and retrieval of the gillnets and therefore, it should not impact the quantity of fish catch, as reported by fishermen.

As a result, this study demonstrates that illuminating artisanal bottom-set gillnets with LED lights lower sea turtle capture rates while having no impact on overall catch rates and quantities of the target fish species. Thus, artisanal bottom-set gillnet fishery off the Kenyan coast may find application for the LED as a by-catch reduction tool.

6.2 RECOMMENDATIONS

Based on this study, the Fisheries department and other key stakeholders should step up their program of sensitization and awareness raising to inform fishers about ethical fishing techniques, government fisheries legislation, and county and local by-laws. The marine fishing industry actors should also make the existing penalties for breaking these rules more severe. The use of small mesh size, seine and light for fishing are some harmful fishing practices that the education program should target since these were identified as major causes of the declining fish stocks.

The wildlife and fisheries laws of Kenya, as well as the county by-laws set by all Kenyan coastal counties for responsible fishing in the study area, should be implemented and enforced to prevent illegal fishing activities in the area and help in the management of the coastal artisanal fishery.

There is a need to have committees on fisheries at the various county, and beach management units where fishing is a major economic activity. This will ensure that issues relating to fishing are given enough attention and resources for challenges to be addressed in a timely and effective manner as need be.

Also, fishing efforts should be properly regulated to help stabilize the increasing pressure on the fishery that at times leads to bycatch. This could be done through several ways such as; fishing quota observation for artisanal fishers, fishing days specification of the vessels and each vessel reducing the net and boat sizes timely as needed. The close season implemented in protected areas should also be sustained to help reduce fishing pressure in unprotected areas.

This study proposes alternative livelihoods for income generation and diversification to be introduced in the study area. These will provide other sources of income aside from fishing and help reduce the pressure on the fishery by reducing the efforts hence bycatch of sea turtles.

The marine and coastal environment should be conserved and the primary obligations should be on coastal communities to adopt proper environmental management and conservation measures to ensure that fishery resources are maintained and not endangered. The measures should include proper environmental stewardship and Locally Manage Marine Areas (LMMA) to address environmental issues in the study area such as marine plastic waste, sea turtles' bycatch, and poaching, mangrove deforestation among others.

A task force and the sea turtles action plan should be put in place to ensure that fishers and other actors do not land marine megafauna including sea turtles that are protected by the existing international and national laws. This will ensure that marine biodiversity is not threatened by fishing operations in the study area and the whole of coastal Kenya.

A fisheries scientific survey of the entire Kenyan coastal area by relevant stakeholders should include comprehensive sea turtle bycatch information gathering in their routine field data collections. This should be stored in a central repository facility or database to afford easy access to the annual bycatch rate in Kenya's artisanal fishery, and allow for comparison between years, locations and fisheries to inform effective management.

The Kenya Wildlife Service, the Forestry Department and the Fisheries Department of Kenya should amend their respective regulations to accommodate new technologies including the use of LED lights on fishing gear, especially the gillnets and driftnets, as a requirement to reduce sea turtle bycatch.

Additionally, behavioral studies of sea turtles are recommended to explore the exact function of the LED lights to help improve the efficiency of the device. It is recommended to determine whether turtles are avoiding the LEDs as a device, or whether the light rays from the LED device help the turtles see the fishing nets better. More studies are recommended to help come up with a lighter, cheaper and more renewable by using solar power instead of reachable batteries.

Further studies are recommended into the impact of environmental conditions on the efficiency of LED light utilization on the Kenyan coastal waters in artisanal gillnet fishery. Further study of the continuity of the traditions and beliefs and how current knowledge and adherence pass this on to the next generation, is also necessary. This is because of the realization from the study that sea turtle-eating beliefs still exist in Kenya's coastal communities.

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APPENDICES

Appendix I. The questionnaire with fishermen

1. How many turtles do you catch in a year? Is turtle bycatch going on even now?

2. More of which turtle species do you catch and why are turtles important?

3. What is the economic cost of turtle bycatch for your fishing operation? How much money is spent per year on what and how many hours are lost per year and why?

4. What proportions are dead if capture happens?

5. Which turtle species do you catch and tend to survive better?

6. What are the main gear types and target catch with which bycatch is associated?

7. During what months do you catch most turtles?

8. How many times did you use the lights? During what months?

9. Do you think you caught fewer turtles when the lights were attached to your nets?

10. Which turtle species was more affected by the lights?

11. What was the influence on target catch? Did you catch more or fewer fish overall? What species did you catch more of, what species did you catch less of? Any influence on octopus, others? Discards?

12. What did you like about the design of the lights?

13. What did you not like about the design of the lights?

14. How could they be improved for your fishing operation?

15. If the lights were freely available and could be modified to your suggestions would you choose to use them?

16. For further research would you be happy to support onboard observers on your vessels to record data?

Appendix II. Fish data collection tool

FISH DATA COLLECTION TOOL

BOAT CAPTAIN NAME:..LANDING SITE NAME:.................

Number ya kutambulisha	Tarehe	Chombo/Aina ya Uvuvi	Aina Ya samaki	Kipimo(kgs) Kadirio.	Bei Ya sokoni/Kilo Kadirio.	Pesa kwa kukadiria	Maelezo

Note: Please tick the boxes to the left of any questions not asked. Provide appropriate ID charts and maps for interviewee to point to during the interview.

Appendix III. Turtle data collection tool

TURTLE DATA COLLECTION TOOL

BOAT CAPTAIN NAME:..LANDING SITE NAME:.................

Individual Record ID	Vessel/ Gear Type	Sighting Record #	# Individuals Seen	Type of Individual (Species)	Habitat	Size S,L	Mother - Hatchling Pair Y / N	Day / Night and time	Date dd/mm /yy	Dead / Alive	Cause	Condition	Accidental / Direct	Reported Y / N	Notes

Habitat Codes: *(D) Deep Water; (C) Coral; (S) Seagrass; (F) Fine Sediments; (M) Mangroves; (R) Rocks; (E) Estuaries; (U) Unknown*

Cause: *(G) Gill net, (O) Other Fishing Gear (specify in notes), (B) Boat Strike, (H) Hunting (D) Don't Know*

Condition: *(F) Fresh, (D) Decomposed*

Note: Please tick the boxes to the left of any questions not asked. Provide appropriate ID charts and maps for interviewee to point to during the interview.

Appendix IV. The lead researcher and an observer fitting LEDs in nets

Appendix V. Research permit

NACOSTI ACCREDITED

ERC/MSc/020/2017R

Pwani UNIVERSITY

ETHICS REVIEW COMMITTEE

ACCREDITTED BY THE NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY AND INNOVATION (NACOSTI, KENYA)

CERTIFICATE OF ETHICAL APPROVAL

THIS IS TO CERTIFY THAT THE PROPOSAL SUBMITTED BY:

KAKAI T. MUNYIKANA

REFERENCE NO:
ERC/MSc/020/2017R

ENTITLED:
Assessing the effectiveness of LED lights in reduction of sea Turtle by-catch and mortality in Gill net fishery along the North Coast of Kenya: Case study of Watamu

TO BE UNDERTAKEN AT:
NORTH COAST, KENYA

FOR THE **PERIOD OF ONE YEAR**

HAS BEEN **APPROVED** BY THE ETHICS REVIEW COMMITTEE

AT ITS SITTING HELD AT PWANI UNIVERSITY, KENYA

ON THE **10TH DAY OF MAY 2018**

CHAIRMAN	SECRETARY	LAY MEMBER

PTO

Pwani UNIVERSITY

Ethics Review Committee,
Pwani University, www.pu.ac.ke, email: r.thomas@pwaniunversity.ac.ke, tell: 0719 182218.
The ERC, Giving Integrity to Research for Sustainable Development

Appendix VI: Consent form

Study Title: Assessing the effectiveness of LED lights for the reduction of sea turtle bycatch in an artisanal gillnet fishery – a case study from the north coast of Kenya

Program: Masters of Science in Environmental Science

Names of supervisors: Dr. Andrew Wamukota and Dr. Nina Wambiji

Researcher: Mr. Timothy Kakai

Admission Number: N50/PU/6005/15

Dear Sir/Madam,

You are invited to take part in a research study being conducted by Mr. Timothy Kakai a Masters student at Pwani University. The purpose of the research is to assess the effectiveness of LED lights for the reduction of sea turtles bycatch in an artisanal gillnet fishery - a case study from the north coast of Kenya. Before you decide to participate in this study, it is important that understand what the research will involve. Please take time to read the instructions carefully. If you need more information, please contact the researcher using the address provided bellow. There are no risks or discomforts that bare anticipated from participation in the study. You may decline to answer any or all questions and you may terminate your involvement at any time you choose. If you do not want to be in the study, you may choose not to participate and leave your answers blank. The information gathered during this study will remain confidential and only the researcher will have access to the study data and information. You are at liberty to include your name on the questionnaire or not. Information gathered will only be used for academic purposes. By signing this consent form, I confirm that I have read understood the information and have had an opportunity to seek clarification. I understand that my participation is voluntarily and that I am free to withdraw at any time. I voluntarily agree to take part in this study.

Name of participant:………………………………………………………

Sign:……………………………………………………………………..

Date:………………………………………………………………......

Name of researcher: Mr. Timothy Kakai

Cell: 0721885068

Sign:………………………………………………………………………

Date:……………………………………………………………….......